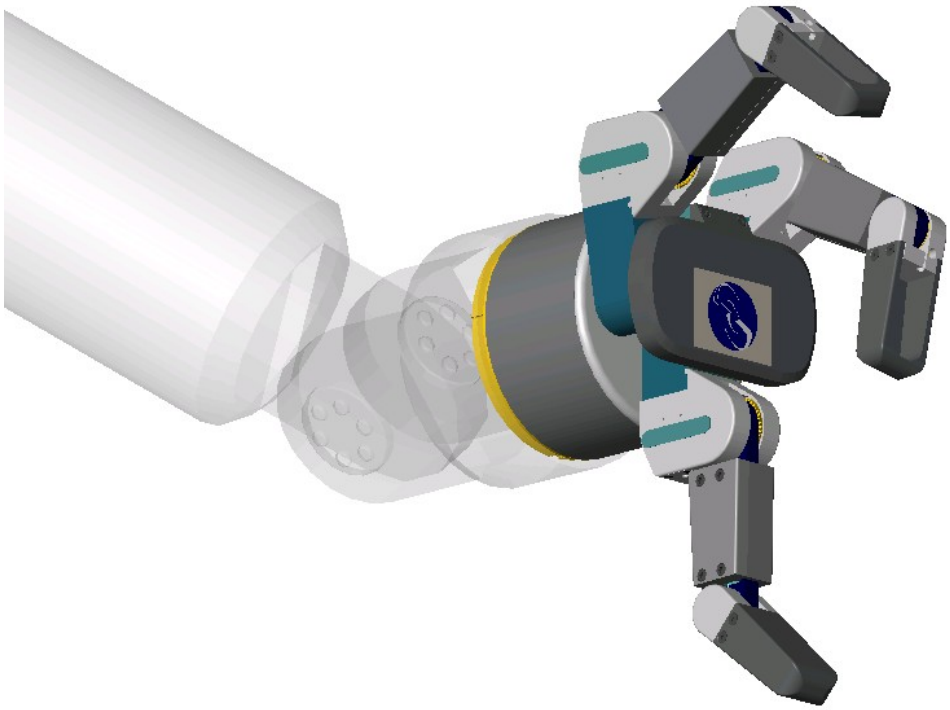
BarrettHand

BH8-255 User Manual



Barrett Technology Inc.

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1 System Description

1.1 Standard BH8-255 System Components

1.1.1 System Features

Thank you for selecting the most versatile robotic hand ever made. The BarrettHand is designed as an affordable, practical compromise between inflexible industrial grippers and highly dexterous, but bulky and expensive research hands. The BarrettHand is lightweight and self-contained like a gripper, but programmable like a dexterous research hand. The BarrettHand is a multi-fingered grasper with the dexterity to secure target objects of different sizes, shapes, and orientations. Even with its low weight (1.18kg) and compact form, it is totally self-contained. Integration with any arm is fast and simple by using industry-standard serial communications.

The BarrettHand is ideal for mounting on almost any robot arm due to its compact and lightweight construction. Its low mass and short base-to-graspcenter distance minimize joint loading on the host robot and reduce extraneous arm movements during object reorientation. The custom control-electronics package is contained entirely within the palm shell, reducing electrical wiring to a single cable carrying all communications and motor power.

1.1.2 Documentation

Barrett Technology provides two different manuals to assist you in learning about the BarrettHand. The first manual is the BH8-255 User Manual and contains information about:

- System components and options
- System setup and operation
- Maintenance
- Troubleshooting
- Theory of operation
- Technical specifications
- Frequently asked questions

The second manual is the BHControl Interface Manual and is a tool for learning the BHControl Interface. The BHControl Interface is a Windows application and allows you to control the BarrettHand quickly and easily. Refer to this manual for instructions on how to control the BarrettHand.

Both manuals are also in electronic form on the Control Software diskettes.

1.1.3 BarrettHand

The BarrettHand, shown in Figure 1, is comprised of three fingers, two of which rotate about the base joint. The fingers are labeled F1, F2 and F3. Each of the three fingers on the BarrettHand feature two joints driven by a single DC brushless servo motor. Finger joints are coupled through Barrett's patented TorqueSwitch™, which automatically switches motor torque to the appropriate finger joint when closing on a target object. Using the fingers together allows the BarrettHand to "grasp" different objects securely.

The fourth motor moves F1 and F2 in the coupled "spread" motion around the palm, allowing "on-the-fly" grasp reconfiguration to adapt to varying target object sizes, shapes, and orientations. The BarrettHand spread function, in conjunction with the TorqueSwitch™, effectively makes object-grasping target-independent.

The BarrettHand, shown in Figure 1, is equipped with a threaded base for easy mounting. The threaded base is fully compatible with the BarrettArm and, with the optional arm adapter, can be mounted on virtually any robot. This allows for easy installation and maintenance of the BarrettHand.

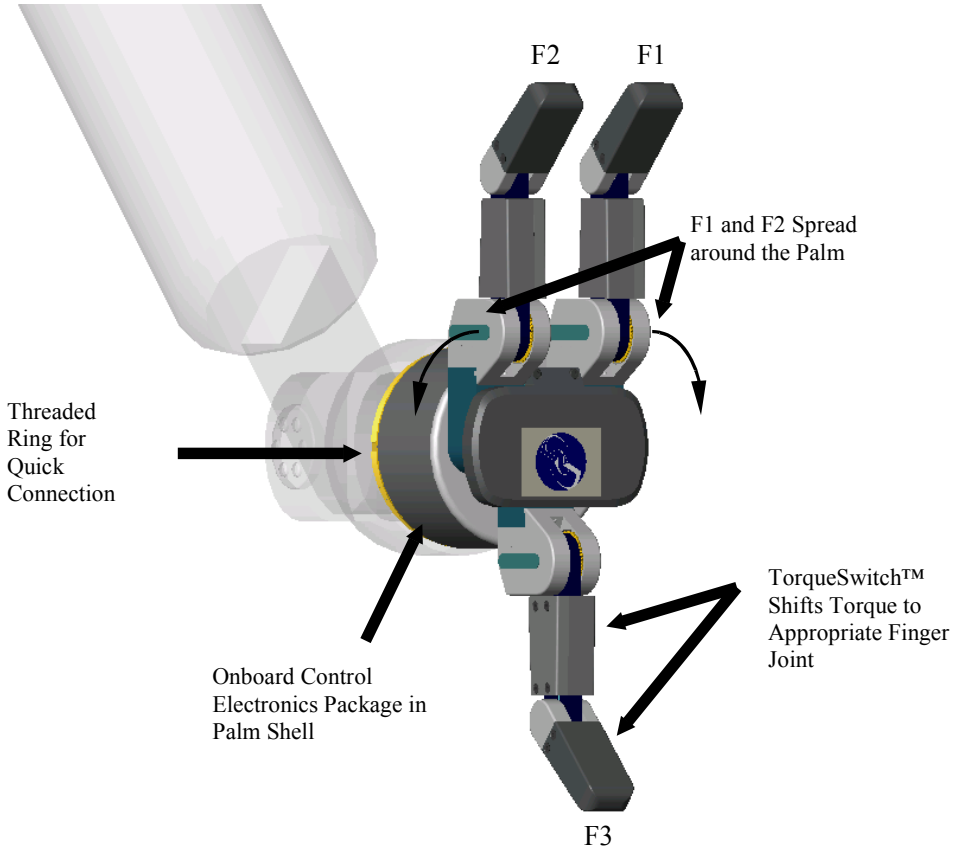
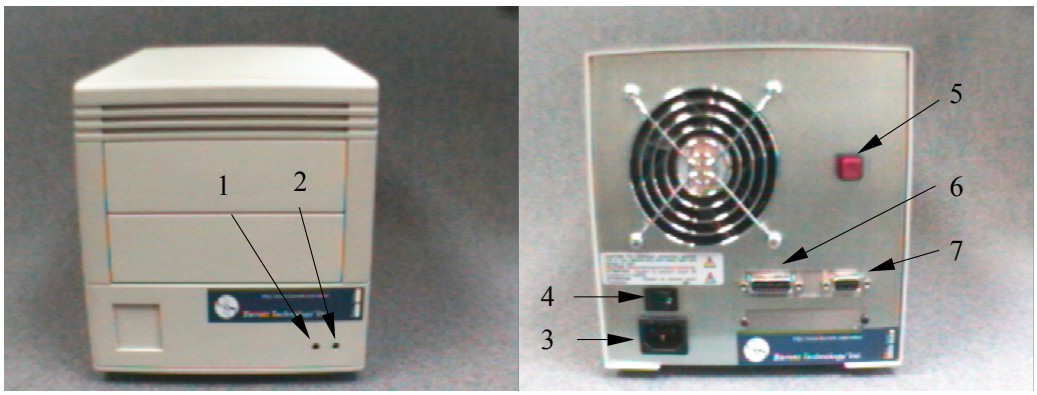


Figure 1 - BarrettHand

1.1.4 Power Supply

The Power Supply, shown in Figure 2, provides all DC motor bus voltage, electronic component logic voltage and passes RS-232 commands from the host computer to the control electronics in the BarrettHand palm shell. This Power Supply auto-switches for international voltage standards and contains built-in surge protection, shielding an attached BarrettHand from surges in the AC line-voltage.

The three connections to the Power Supply are the AC line voltage, RS-232 connection from the host computer and a connection for carrying signal and power to and from the BarrettHand. The Power Supply is also equipped with a button to reset the BarrettHand and two LED's indicating the presence of proper voltage levels. The red LED, when illuminated, indicates valid 36 V motor power. The green LED, when illuminated, indicates valid 5 V logic power. Refer to Figure 2 for a detailed picture of the Power Supply.



1. Red LED - 36 V monitor
2. Green LED - 5 V monitor
3. AC line cord connector
4. Power Switch
5. Reset Switch
6. 15 pin female BarrettHand Cable connector
7. 9 pin female Serial Cable connector

Figure 2 - BarrettHand Power Supply

1.1.5 Lab Bench Stand

The bench mount stand for the BarrettHand, shown in Figure 3, is ideal for use in a laboratory environment. The durable Lexan® stand comes complete with cable management clips and mounting feature to hold your BarrettHand unit securely on any flat surface. Non-slip rubber feet keep the stand from sliding during testing and programming.

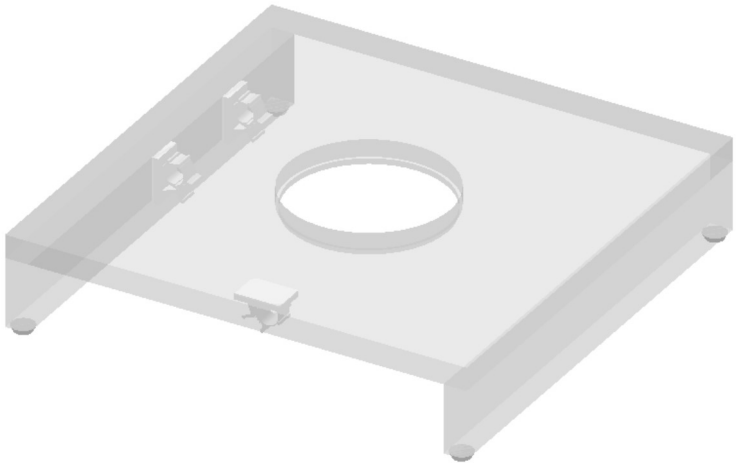


Figure 3 - Lab Bench Stand

1.1.6 Electrical Cables

All necessary electrical cables are included in the basic BH8-255 System. An AC line cord connects the Power Supply to a wall source, 120/240 ±10% VAC. A serial cable connects the Power Supply and the host computer to establish the RS-232 communication link. The BarrettHand Cable connects the Power Supply to the BarrettHand, supplying communications, logic power, and motor power. This cable is extremely flexible allowing the BarrettHand to be used on any robot with minimal effect on robot performance. Use the included set of twelve adhesive guide clips for cable management. Since the control hardware resides inside the BarrettHand itself, no other electrical cabling is required.

1.1.7 Control Software and Firmware

The BH8-255 System control software consists of the BHControl Interface Application and Manual, BH8-255 User Manual, latest firmware version and example programs. The BHControl Interface is a Windows application that allows you to control the BarrettHand quickly and easily. The BHControl Interface can be used to test Supervisory and RealTime control sequences, measure communication loop rates, demonstrate functionality, learn how to write

and automatically generate C code independently, based on tested algorithms. See Section 4.2 for more information on Supervisory and RealTime control and the BHControl Interface Manual for more information on the BHControl Interface.

The BarrettHand has firmware that resides on the control electronics. The firmware requires only ASCII characters sent over a standard serial port. You build the character strings to create the desired commands. The firmware then interprets the commands sent and controls the motors, sets and retrieves parameters, or reads and writes to the EEPROM. See Section 4.2 for more information on firmware commands and parameters.

1.1.8 Maintenance Kit

Included in each BarrettHand package is a maintenance kit. Use the maintenance kit in accordance with the instructions in Section 5. The maintenance kit includes the following:

- 1.0-mm Hex wrench
- 1.27-mm Hex wrench
- 2.0-mm Hex wrench
- 2.5-mm Hex wrench
- Mobil 1® Lubricant in syringe
- Lubricant applicators
- Torque wrench
- 2.0-mm Hex adapter for Torque wrench

1.2 System Options

1.2.1 Arm adapter

Barrett Technology can provide an arm adapter for any make or model robot. This lightweight arm adapter is made to work with the end-effector bolt pattern on your robot, allowing quick, easy mounting and wire management for a BH8-255 System. The arm adapter is bolted to the end of the robot arm and the BarrettHand is secured to the arm adapter with its standard threaded locking ring, see Figure 4. The arm adapter is also equipped with an anti-rotation feature to prevent rotation during operation.

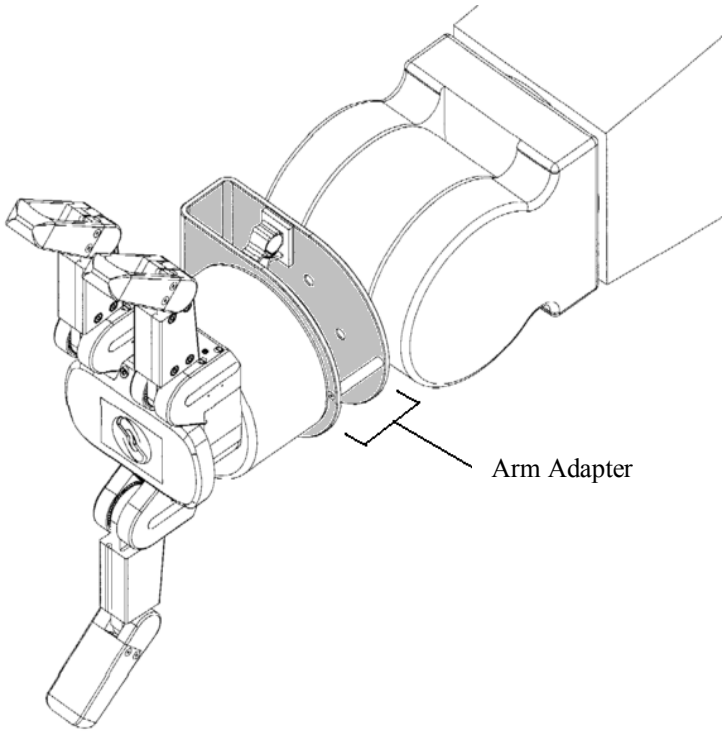


Figure 4 - Arm adapter

1.2.2 C-Function Library

The BarrettHand C-Function Library is a helpful tool for programming the BarrettHand using the C language on IBM-compatible PC's without having to manage serial communication and timing issues. The library contains easy-to-use functions that permit the use of Supervisory and RealTime commands in software routines developed by the end user. All of the functions are available when the library is linked to the program. The C-Function Library also includes a manual that describes all of the functions in detail and gives examples.

one object and use it for all communications.. The library uses a sophisticated multithreaded mechanism for accessing the serial port, which allows both synchronous and asynchronous access to the low-level thread and ensures that all serial communications are executed with high priority. The low-level thread manages all input and output buffers and makes controlling the BarrettHand easy.

1.2.3 Strain gage Joint-Torque Sensors

Barrett Technology offers a factory-installed torque sensor for the BH8-255 System. This option uses strain gages to measures the differential tension in the "tendon" running through each finger to the second joint. The information is processed in additional onboard circuitry and can be accessed by requesting the present strain gage parameter. The strain gage parameter represents the amount strain on the strain gage sensors. The strain gage values need to be calibrated by the customer to relate strain to joint torque. The joint torque for the second finger joint is over a 1.0 N-m range (approximately 0.1 N-m resolution). See Section 7.4 for more detailed information on how the sensor works.

1.2.4 Control Software/Firmware Upgrades

Barrett Technology makes software and firmware upgrades periodically. Upgrades are available for purchase or free of charge for customers of Barrett's subscription service. Refer to Barrett's enclosed Warranty and Subscription Service Policy for more information.

2 Safety and Cautions

PLEASE READ THIS SECTION IN ITS ENTIRETY BEFORE USING YOUR BARRETTHAND.

Following these safety instructions will help prevent user injury and equipment damage.

- As with any piece of robotic equipment, it is ultimately up to you to be aware of your surroundings during robot operation. The workspace of the BarrettHand (whether attached to a robot arm or its lab bench stand) should be clearly marked to prevent persons or objects from inadvertently entering the equipment's reach. Before attaching the BarrettHand, test host robot trajectories to confirm that it will not inadvertently collide with other objects in the workspace.

- NEVER connect or disconnect any electrical cables while the Power Supply is turned on. Failure to follow this instruction could impart irreparable damage to the onboard electronics or put you at risk of electrical shock.

- Always plug the Power Supply into a properly grounded wall source. Failure to do so could damage the BarrettHand electronics and put you at risk of electrical shock.

- Do not place any part of your body or delicate objects within the grasp of the BarrettHand without first verifying control of the unit and confirming appropriate force levels.

- Do not allow the BarrettHand to be exposed to liquids that may cause electrical short-circuits and put you at the risk of electrical shock.

- Keep dirt away from the exposed gear and cable drives located at the joints.

- Do not exceed the load limit of the fingers, 2 kg per finger at any point along the outer link. Consider all loading situations including accelerated loads, cantilever loads from long objects, robot collisions, active loads, etc.

- A portion of the onboard control electronics is exposed through the base of the BarrettHand. Before installing to a robot arm, take necessary precautions to protect the electronics from impact, contaminants and static discharge. Do not rest the BarrettHand unit directly on its base. Use the included lab bench stand during standalone operation.

- Remove the fingers only as instructed in Section 5.3.

- Monitor the operating temperature of the BarrettHand so that it does not exceed 65° C. The BarrettHand was designed with non-backdrivable finger joints to take advantage of the motors peak operating performance in short bursts. The spread, however, is backdrivable to aid in target-independent grasping (see Section 7.3.2) and requires constant motor current to actively hold position. Idling the spread motor, when possible, will help keep the temperature lower.

3 System Setup

3.1 Mounting Requirements

3.1.1 Lab Bench Stand

When writing custom programs for the BarrettHand or using the unit without a host robot arm, Barrett Technology recommends using the lab bench stand included and all its wire management clips as shown in Figure 5. These clips prevent the cable from pulling out of the BarrettHand while the Power Supply is turned on. Under no circumstances should the BarrettHand be operated while resting unsecured on a tabletop or any other surface.

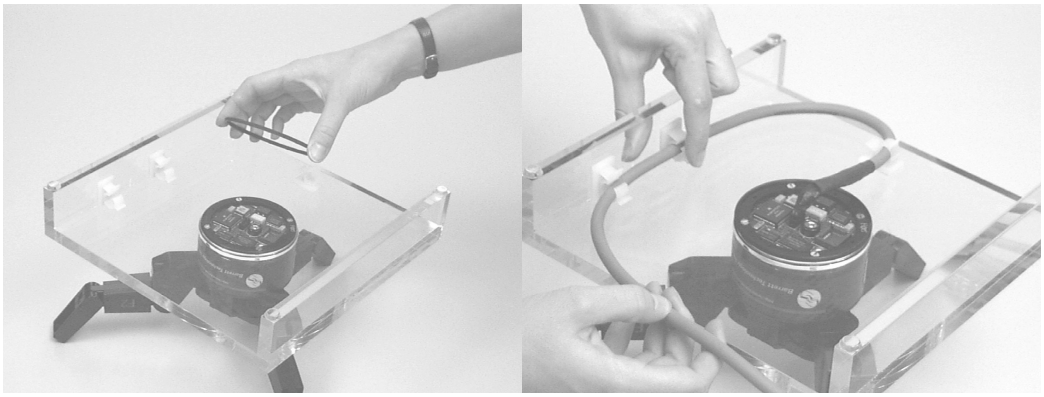


Figure 5 - Lab Bench Stand with Wire Strain Relief

To secure the BarrettHand to the lab bench stand, flip the stand upside down. Pass the base ring of the BarrettHand up through the center hole of the stand and retain it with the threaded locking ring provided with your system, see Figure 5. Note the alignment of the BarrettHand, relative to the wire strain relief clips, to ease connection of the BarrettHand Cable.

Make sure the Power Supply is turned OFF, route the BarrettHand Cable through all three cable clips on the lab bench stand and plug it into the BarrettHand. Tighten the cable clips to hold the cable in place.

3.1.2 Optional Arm Adapter

Like the lab bench stand, the arm adapter is made to retain the BarrettHand in place and to handle wiring from the hand, see Figure 6. The arm adapter, however, can be designed for mounting on your specific robot arm.

To mount your BarrettHand on a robot, bolt the arm adapter onto the end-effector bolt circle. Insert the threaded base of the BarrettHand through the hole in the arm adapter shown in Figure 6 paying attention to the indexing tabs in the arm adapter. These tabs fit into the mating slots on the base of the BarrettHand.

Secure the BarrettHand by threading the locking ring (included with your system) onto the base of the BarrettHand

The BarrettHand Cable is extremely flexible and should be routed close to the center of each revolute joint and along the axis of travel for prismatic joints. Mount the cable clips to a flat, dry and clean surface. Clean cable clip attachment areas with alcohol before attaching. Verify the Power Supply is turned OFF, then route the BarrettHand Cable through the cable retaining clips on the robot and the arm adapter and plug into the BarrettHand and the Power Supply. Tighten the cable clips to hold the cable in place.

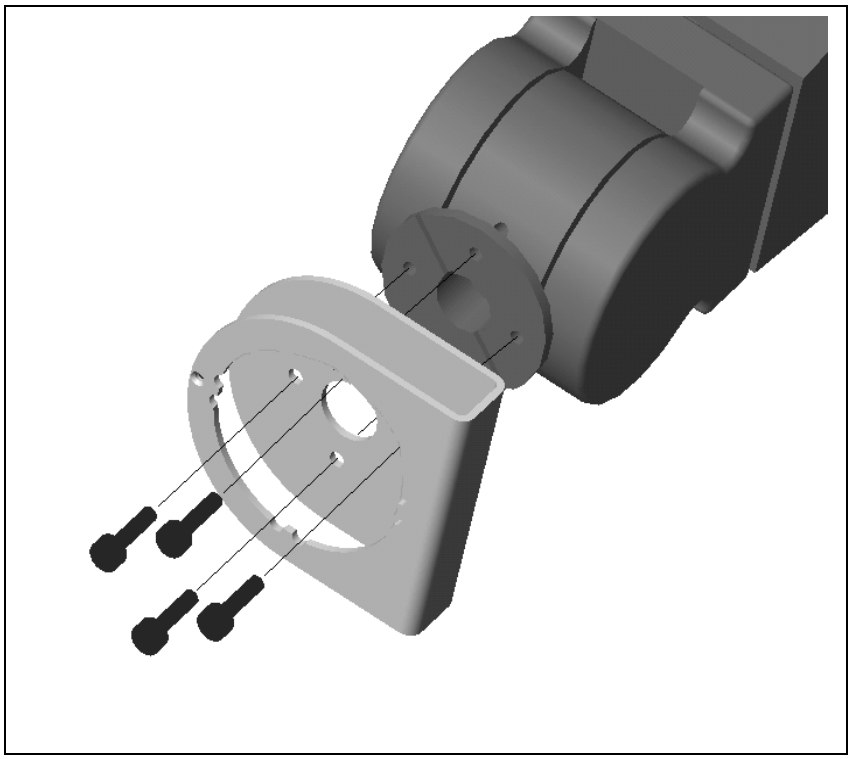


Figure 6 - Installing an Arm Adapter

3.2 Electrical Connections

After mounting the BarrettHand according to Section 3.1, you should connect the electrical cables required for operation.

Check the Power Supply to confirm that it is turned OFF.

- Verify the Power Supply is on a flat, stable surface.
- Plug the free end of the BarrettHand Cable into the female 15 pin D-sub connector on the back of the Power Supply.
- Plug the serial cable into the computer's serial port (usually COM1).

- Plug the other end of the serial cable into the female 9 pin D-sub connector on the back of the Power Supply. Barrett Technology supplies a standard 3-meter straight through serial cable, but you may purchase a longer cable if desired.
- Connect the AC line cord to the socket on the back panel.
- Plug the other end of the AC line cord into a suitable AC wall source.

3.3 Host Computer

The BH8-255 Control Software was written for computers running Windows 95/98/NT 4.0. Barrett Technology recommends using a Pentium based processor with a minimum CPU clock speed of 266 MHz and 32 Mbytes of RAM. The software requires 10 Mbytes of free disk space.

3.4 Installing BH8-255 Control Software

The BH8-255 Control Software consists of the BHControl Interface, firmware and example programs. The BHControl Interface is a Windows API that allows you to control the BarrettHand quickly and easily. The BHControl Interface can be used to test Supervisory and RealTime control sequences, communication loop rates, demonstrate functionality, learn how to independently write C code and automatically generate C code based on tested algorithms[1]. Run the *setup.exe* program on the disk labeled *BH8-255 Control Software Disk 1 of 5*. This will install all necessary files for using the BHControl Interface, the most recent version of firmware, online manuals and example programs.

3.5 Download Firmware

The BarrettHand has firmware that resides in the onboard electronics. This firmware is stored in RAM that receives its power from the Power Supply when the system is turned on and from an embedded super capacitor when powered down. This super capacitor maintains the firmware in RAM from one day up to one week, before the capacitor is fully discharged and the memory is cleared.

When the firmware has been cleared, it will need to be reinstalled. The download process takes only a few minutes, as follows:

1. Verify BarrettHand is plugged into the Power Supply.
2. Verify the host computer is plugged into the Power Supply.
3. Verify the Power Supply is attached to a power source and turned on.
4. Run the BHControl Interface program *BHControl.exe*.
5. Initialize the software by pressing the *Initialize Library* button.
6. Press the *Start Download* button.
7. Open the appropriate file according to Table 1.

[1] The code generated by the Control Interface requires the C-Function Library to compile.

8. Press Reset on the Power Supply.
9. After downloading the file, the BarrettHand is ready for operation.

Table 1 - Firmware File List

File Name	Description
BarrettHand Firmware v3_0.S19	Version 3.0 Firmware
BarrettHand Firmware v4_02.S19	Version 4.02 Firmware with RealTime mode capabilities.

4 BarrettHand Operation

4.1 Power-Up Sequence

Once the steps in Section 3 are complete, your BH8-255 System is ready for use. Power up the system according to the instructions below.

1. Turn on the host computer.
2. Verify the serial cable is plugged into the desired communications port and into the 9-pin connector on the back of the Power Supply.
3. Verify the BarrettHand Cable is plugged into the 15-pin connector on the back of the Power Supply and into the bottom of the BarrettHand.
4. Verify the AC line cord is plugged into a valid power source (see 7.6) and into the power outlet on the back of the Power Supply.
5. Turn on the Power Supply. The main power switch is located on the back panel.
6. The BarrettHand is now ready for operation.

4.2 BarrettHand Control

This section will explain the command structure to communicate with the BarrettHand. The BarrettHand C-Function Library incorporates functions that build and send these commands for you. However, if you choose not to use the C-Function Library, the BarrettHand expects commands in the following format.

4.2.1 Supervisory Control

The BarrettHand can be used in either a high-level Supervisory mode or a low-level RealTime mode. Supervisory mode allows you to command individual or multiple motors to close, open and move to specific positions. You also have access to all of the parameters, which are listed in Section 4.2.3. This set of commands is commonly used for most grasping situations. If real-time control of the motor position, velocity or strain is needed, use the RealTime control described in Section 4.2.5.

Supervisory mode accepts commands from the user program and will not return control of the BarrettHand until the command is finished being processed. The BarrettHand expects valid commands and will return a status code for an invalid command or if another problem occurs. See Section 4.2.6 for more detailed information on status codes. When the command is finished being executed, all status codes and requested information have been sent, the hand will return the command prompt "=>". At this point, you can send another command.

4.2.2 Command Structure

Firmware resides on the BarrettHand and interprets the commands it receives. This command structure allows you to build the desired command easily. The format is as follows:

<Motor><Command> <Parameter> <Value>

Following is a list of the *<Motor>* prefixes:

Table 2 - Motor Prefixes

Value	Motor
1	Finger F1
2	Finger F2
3	Finger F3
4	Spread
G	Finger F1, Finger F2, Finger F3
S	Spread
<No Motor Specified>	Finger F1, Finger F2, Finger F3, Spread (see the Firmware Parameter EN in Section 4.2.3)

Note: Any combination of motor prefixes can be used together to produce the desired result. Example: 12<Command> <Parameter> <Value> will activate Fingers F1 and F2.

See Sections 4.2.3 and 4.2.4 for parameter value and command information.

4.2.3 Firmware Parameters

Parameter: **ACCEL**
Purpose: Acceleration value for position control.
Values: 0 - 32767
Default: Grasp: 1
Spread: 1
Notes: See Section 7.2 for more detailed description of how ACCEL affects motion.

Parameter: **BAUD**
Purpose: Returns the current baud rate of the hand divided by 100.
Values: 6, 12, 24, 48, 96, 192 and 384
Default: 96
Notes: The value returned is in hundreds of bytes per second. To determine the actual baud rate, multiply the value returned by 100.

Parameter: **DP**
Purpose: This parameter defines the default position for a move command.
Values: 0 - 20000 encoder counts
Default: 150 (Spread), 1000 (Fingers)
Notes: None.

Parameter: **DS**
Purpose: This parameter defines default step sizes for incremental open and close commands.
Values: 0 - 20000 encoder counts
Default: 150 (Spread), 1200 (Fingers)
Notes: None.

Parameter: **EN**
Purpose: Specifies if a motor should be selected when a command has no prefix.
Values: TRUE (selected), FALSE (not selected)
Default: Grasp: TRUE
Spread: TRUE
Notes: When a close command is issued, C, with no motor prefixes, all motors will close with the default values.

Parameter: **FDZ**
Purpose: Derivative zero value for the motor control filter.
Values: 0 - 255
Default: Grasp: 221
Spread: 221
Notes: See section 7.2 for more detailed description of how FDZ affects motion.

Parameter: **FIP**
Purpose: Integral pole value for the motor control filter.
Values: 0 - 255
Default: Grasp: 66
Spread: 66
Notes: See section 7.2 for more detailed description of how FIP affects motion.

Parameter: **FPG**
Purpose: Proportional gain value for the motor control filter.
Values: 0 - 255
Default: Grasp: 200
Spread: 100
Notes: See Section 7.2 for more detailed description of how FPG affects motion.

Parameter: **HOLD**
Purpose: Specifies if a motor should hold position when idled.
Values: TRUE (hold position), FALSE (do not hold position)
Default: Grasp: FALSE
Spread: TRUE
Notes: Because the fingers are not backdrivable when the motors are idled they will not be able to move freely. However, because the spread is backdrivable it requires this parameter be TRUE to hold its position when idled.

Parameter: **LCPG**
Purpose: This flag specifies if the RealTime control block contains control proportional gain.
Values: FALSE (does not contain), TRUE (does contain)
Default: FALSE
Notes: Motor command = (LCPG / 4) * (Control Velocity - Actual Velocity)

Parameter: **LCV**
Purpose: This flag specifies if the RealTime control block contains control velocity.
Values: FALSE (does not contain), TRUE (does contain)
Default: TRUE
Notes: The size of the control velocity should be 1 signed byte.

Parameter: **LCVC**
Purpose: LCV is multiplied by the control velocity coefficient (LCVC) to determine the control velocity.
Values: 0 - 255
Default: 1
Notes: Control velocity = LCV * LCVC

Parameter: **LFAP**
Purpose: This specifies if the RealTime feedback block contains the feedback absolute position.
Values: FALSE (does not contain), TRUE (does contain)
Default: TRUE
Notes: The size of the feedback absolute position should be an unsigned 2-byte word.

Parameter: **LFDP**
Purpose: This flag specifies if the RealTime feedback block contains the feedback delta position.
Values: FALSE (does not contain), TRUE (does contain)
Default: FALSE
Notes: The size of the feedback delta position should be 1 signed byte.

Parameter: **LFDPC**
Purpose: The actual change in position is divided by feedback delta position coefficient (LFDPC) to determine LFDP.
Values: 0 - 255
Default: 1
Notes: Delta position is the change in position from the last reported position and is limited to one signed byte. The current position is read and compared to the last reported position. The difference is divided by the RealTime variable LFDPC, clipped to a single signed byte, and then sent to the host. The value sent to the host should be multiplied by LFDPC and then added to the last reported position.

Parameter: **LFS**
Purpose: This specifies if the RealTime feedback block contains the feedback strain gage value.
Values: FALSE (does not contain), TRUE (does contain)
Default: TRUE
Notes: The size of the feedback strain gage value should be 1 unsigned byte.

Parameter: **LFV**
Purpose: This specifies if the RealTime feedback block contains feedback velocity.
Values: FALSE (does not contain), TRUE (does contain)
Default: TRUE
Notes: The size of the feedback velocity should be 1 signed byte. The actual velocity is LFC*LFVC.

Parameter: **LFVC**
Purpose: Actual velocity is divided by feedback velocity coefficient (LFVC) to determine LFV.
Values: 0 - 255
Default: 1
Notes: On the host computer the actual velocity of the motors is equal to LFV * LFVC.

Parameter: **MCV**
Purpose: This parameter defines the maximum close velocity.
Values: 0 - 255
Default: 35 (Spread), 65 (Fingers)
Notes: See Section 7.2 for more information on velocity.

Parameter: **MOV**
Purpose: This parameter defines the maximum open velocity.
Values: 0 - 255
Default: 35 (Spread), 55 (Fingers)
Notes: The minimum velocity required to reset the TorqueSwitch™ and open and close the fingers is 40. See Section 7.2 for more information on velocity.

Parameter: **MPE**
Purpose: Maximum position error allowed for a commanded position.
Values: 0 - 30,000
Default: Grasp: 25
Spread: 25
Notes: If the final position is not within +/- MPE encoder counts of the desired position then the hand will return an error.

Parameter: **MSG**
Purpose: This parameter defines the maximum strain gage value before the motor is stopped.
Values: 0 - 256
Default: 256
Notes: Setting the value to 256 indicates that the strain gage value will never stop the motors.

Parameter: **P**
Purpose: This parameter specifies the present motor position.
Values: 0 - 20000 encoder counts
Default: N/A
Notes: This parameter can not be set.

This section lists all of the firmware parameters and their values for BarrettHand.
Parameter: **S**
Purpose: This parameter defines the current state of the motor.
Values: 0 (motor found and initialized) or 1 (motor not initialized)
Default: N/A
Notes: This parameter can not be set.

Parameter: **SG**
Purpose: This parameter specifies the current strain gage value.
Values: 0 - 255
Default: N/A
Notes: This parameter can not be set.

Parameter: **SGFLIP**
Purpose: Specifies if the reported strain should be (255 - actual strain).
Values: TRUE (reported strain = (255 - actual strain)), FALSE (reported strain = actual strain)
Default: Grasp: FALSE
Spread: N/A
Notes: Setting this value will inverse the direction of the change in strain for a given torque.

Parameter: **TEMP**
Purpose: Returns the present temperature on the CPU board in tenths of degrees Celsius.
Values: -550 to 1250
Default: N/A
Notes: The value returned is in tenths of degrees. To determine the actual temperature, divide the value by 10.

Parameter: **TSTOP**
Purpose: Time in milliseconds before the motor is considered stopped.
Values: 0 - 32767
Default: Grasp: 30
Spread: 30
Notes: None.

4.2.4 Firmware Commands

Command: **C**
Function: Closes specified motors.
Parameters: N/A
Notes: None.

Command: **ERR**
Function: Returns a description of the status code specified.
Parameters: Status code numbers.
Notes: Does not take motor prefixes. See Section 4.2.6 for more information on status codes.

Command: **FDEF**
Function: Loads the factory default values of the parameters from EEPROM into memory.
Parameters: N/A
Notes: This command loads the following parameters: MCV, MOV, DS, MSG, DP, FPG, FIP, FDZ, EN, SGFLIP, ACCEL, MPG, TSTOP, HOLD, LCV, LCVC, LCPG, LFV, LFVC, LFS, LFAP, LFAP, LFDPC.
See Section 4.2.3 for the default parameter values.

Command: **FGET**
Function: Gets the specified parameters.
Parameters: MOV, MCV, MSG, DS, DP, LCV, LCVC, LCPG, LFV, LFVC, LFS, LFAP, LFDP, LFDPC, FPG, FIP, FDZ, ACCEL, MPE, TSTOP, HOLD, SGFLIP, EN, BAUD, S, P, SG
Notes: See Section 4.2.3 for more information on firmware parameters.

Command: **FLISTA**
Function: Lists all of parameters and their read/write status.
Parameters: N/A
Notes: Does not take motor prefixes.

Command: **FLISTAV**
Function: Lists all of the present parameter values.
Parameters: N/A
Notes: The parameters are listed in the same order they are displayed by the command FLISTA. This command does not take motor prefixes.

Command: **FLOAD**
Function: Loads the saved parameters from EEPROM into memory.
Parameters: N/A
Notes: This command loads the following parameters: MCV, MOV, DS, MSG, DP, FPG, FIP, FDZ, EN, SGFLIP, ACCEL, MPG, TSTOP, HOLD, LCV, LCVC, LCPG, LFV, LFVC, LFS, LFAP, LFAP, LFDPC.
See Section 4.2.3 for the parameter definitions.

Command: **FSAVE**
Function: Saves the present values of the parameters to EEPROM.
Parameters: N/A
Notes: This command saves the following parameters: MCV, MOV, DS, MSG, DP, FPG, FIP, FDZ, EN, SGFLIP, ACCEL, MPG, TSTOP, HOLD, LCV, LCVC, LCPG, LFV, LFVC, LFS, LFAP, LFAP, LFDPC.
See Section 4.2.3 for the parameter definitions.

Command: **FSET**
Function: Sets the specified parameters to the desired value.
Parameters: MOV, MCV, MSG, DS, DP, LCV, LCVC, LCPG, LFV, LFVC, LFS, LFAP, LFDP, LFDPC, FPG, FIP, FDZ, ACCEL, MPE, TSTOP, HOLD, SGFLIP, EN, BAUD
Notes: See Section 4.2.3 for information on the firmware parameters.

Command: **HI**
Function: Initializes the finger and spread motors. Opens all of the joints to their full open position and sets it to be zero.
Parameters: N/A
Notes: The BarrettHand will vibrate the joints during this operation. This command needs to be executed before any motion commands.

Command: **IC**
Function: Incremental close for specified motors.
Parameters: N/A
Notes: The increment size is defined in the parameter DS.

Command: **IO**
Function: Incremental open of specified motors.
Parameters: N/A
Notes: The increment size is defined in the parameter DS.

Command: **LOOP**
Function: Enters RealTime mode for the specified motors
Parameters: N/A
Notes: See Section 4.2.5 for more information on how the RealTime mode functions.

Command: **M**
Function: Move the specified motors to specified position
Parameters: Motor position, 0 - 20000
Notes: If no position is given it will move to the value stored in DP.

Command: **O**
Function: Opens specified motors.
Parameters: N/A
Notes: None.

Command: **PGET**
Function: Gets the parameter specified.
Parameters: TMP
Notes: Does not take motor prefixes.

Command: **RESET**
Function: Resets the BarrettHand and loads all of the saved parameters from EEPROM.
Parameters: N/A
Notes: Does not take motor prefixes. The motors need to be reinitialized before commanding motion after using this command. See the command FSAVE for parameter information.

Command: **T**
Function: Stops actuating the motors.
Parameters: N/A
Notes: None.

Command: **VERS**
Function: Greeting message, shows the version number and the company contact information.
Parameters: N/A
Notes: None.

Command: **?<Command>**
Function: Help information about the <Command> specified.
Parameters: N/A
Notes: None.

Command: **^C**
Function: Stops the motors and clears the input buffer. A new prompt will be output.
Parameters: N/A
Notes: None.

4.2.5 RealTime Control

One features of the BarrettHand is the RealTime control. This control mode allows you to send commands and receive feedback continuously from the BarrettHand. Any desired control law can be applied by using the host computer to determine the desired motor command and then applying that command to the BarrettHand in real-time. The communication bandwidth is dependent on the amount of control information sent, feedback information requested and the selected baud rate.

Data from the host computer to the hand is grouped into control and feedback blocks. Each block has a single byte header, followed by a set of data. The control block header specifies whether or not control data is to follow, and whether or not a feedback block is to be returned. The feedback block header returned acknowledges the receipt of the control block or indicates an error. The control block header can also terminate the loop mode.

The possible control block header bytes are:
"C": Control data follows; respond with a feedback block
"c": Control data follows; respond with an acknowledgement character ("*")
"A": No control data follows; respond with a feedback block
"a": No control data follows; respond with an acknowledgement character
"^C": Terminate loop mode

The possible feedback block header bytes are:
"*": The BarrettHand has received the control block successfully.
"<CRLF>ERR": An error occurred, the status code will follow immediately.

Before sending information to the BarrettHand in RealTime mode, it is necessary to determine what the control and feedback blocks will contain. Do this by setting the RealTime control flags before entering RealTime mode. Setting a flag TRUE indicates that it will be part of the control or feedback block. A flag for each motor needs to be set. Set the flags by using the FSET command. See Table 3 for a detailed description of the flags.

There are also three RealTime variables that need to be set before entering RealTime mode. These three variables affect how the RealTime control values are interpreted. Set these variables by using the FSET command. See Table 3 for a detailed description of the variables.

Table 3 - RealTime Control Parameters

Parameter	Name	Type	Function	Size in Block
LCV	Loop Control Velocity	Flag	If True, RealTime control block will contain control velocity	1 signed byte
LCVC	Loop Control Velocity Coefficient	Variable (integer)	LCV is multiplied by LCVC to determine control velocity	N/A
LCPG	Loop Control Proportional Gain	Flag	If True, RealTime control block will contain Proportional Gain	1 unsigned byte
LFV	Loop Feedback Velocity	Flag	If True, RealTime feedback block will contain feedback velocity	1 signed byte
LFVC	Loop Feedback Velocity Coefficient	Variable (integer)	Actual velocity is divided by LFVC to get LFV	N/A
LFS	Loop Feedback Strain	Flag	If True, RealTime feedback block will contain strain information	1 unsigned byte
LFAP	Loop Feedback Absolute Position	Flag	If True, RealTime feedback block will contain absolute position	2 unsigned bytes
LFDP	Loop Feedback Delta Position	Flag	If True, RealTime feedback block will contain delta position	1 signed byte
LFDPC	Loop Feedback Delta Position Coefficient	Variable (integer)	The actual delta position is divided by this to get LFDP	N/A

Now that all of the flags and variables have been set, it is time to begin RealTime control. Send the command <Motors>LOOP to enter RealTime mode. At this point the BarrettHand will respond with a "*" to acknowledge the start of RealTime control. It is now up to the host computer to build control blocks and send them to the BarrettHand.

Example:
This application uses fingers F1 and F2, and the spread. The fingers will receive velocity control information and report strain and delta position. The spread will just report delta position. All relevant coefficients will be set to 1.

Set the RealTime flags and variables by using the following commands:
12FSET LCV 1 LCVC 1 LCPG 0 LFV 0 LFS 1 LFAP 0 LFDP 1 LFDPC 1
4FSET LCV 0 LCVC 1 LCPG 0 LFV 0 LFS 0 LFAP 0 LFDP 1 LFDPC 1

Enter RealTime control by issuing the following command.

124LOOP
The BarrettHand will then send a single "*" and wait for control blocks. Each control block will consist of three bytes:

"C" [Control data follows; respond with feedback block]
1 signed byte of velocity for motor F1
1 signed byte of velocity for motor F2

Each feedback block will consist of six bytes:
"*" acknowledge character
1 unsigned byte of strain for motor F1
1 signed byte of delta position for motor F1
1 unsigned byte of strain for motor F2
1 signed byte of delta position for motor F2
1 signed byte of delta position for motor 4

Each control block from the host will stimulate a feedback block from the BarrettHand. When the host is finished, it will send the single character ^C (0x03); the BarrettHand will respond by printing the command prompt "=>", and waiting for a new command.

4.2.6 Status Codes

Status codes, see Table 4, are sent by the BarrettHand when the communication was successful, but the BarrettHand encountered a problem. Keep in mind that BarrettHand status codes are powers of 2, so the return value may encode multiple flags. Example: a status code of 3, indicates status code 2 and status code 1.

Table 4 - Hand Status Codes

Hand Status Code	*Description*
1	No motor board found
2	No motor found
4	Motor not initialized
8	not used
16	Couldn't reach position
32	Unknown command
64	Unknown parameter name
128	Invalid value
256	Tried to write a read only parameter
512	Timeout
1024	Too many arguments for this command
2048	Invalid RealTime control block header
4096	Command can't have motor prefix

4.3 Example Programs

4.3.1 Supervisory Mode Example Program

The following program is an example that shows how to program the BarrettHand in Supervisory mode using the C-Function Library. The code was generated using the BHControl Interface and compiled using Microsoft Visual C++ v6.0. This program initializes the BarrettHand and then opens and closes the grasp.

```
////////////////////////////////////////////////////////
//                                                    //
//           Automatically Generated C++ Code         //
//           BHand Control Center Version 1.0         //
//                                                    //
//                   Supervisory Mode                 //
//                                                    //
////////////////////////////////////////////////////////

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include "BHand.h"

BHand  bh;           // Handles all hand communication
int    value;        // Hand parameter obtained with Get command
int    result;       // Return value (error) of all BHand calls

////////////////////////////////////////////////////////
// Error Handler - called whenever result!=0

void Error(void)
{
      printf( "ERROR: %d\n%s\n",result,bh.ErrorMessage(result));
      exit(0);
}


////////////////////////////////////////////////////////
//  Initialize hand, set timeouts and baud rate

void Initialize(void)
{
      if(result=bh.InitSoftware(1,THREAD_PRIORITY_TIME_CRITICAL))
            Error();
      if( result=bh.ComSetTimeouts(0,100,15000,100,5000) )
            Error();
      if( result=bh.Baud(9600) )
            Error();
      if( result=bh.InitHand("") )
            Error();
}


////////////////////////////////////////////////////////
//  Execute commands, return 1 if interrupted with a key
```

```
int Execute(void)
{
      printf( "Press Any Key to Abort..." );

      // Initializes all motors
      if( result=bh.InitHand( "123S" ) )
            Error();
      if( _kbhit() )
            { _getch(); return 1; }

      // Closes fingers F1, F2 and F3
      if( result=bh.Close( "123" ) )
            Error();
      if( _kbhit() )
            { _getch(); return 1; }

      // Opens fingers F1, F2 and F3
      if( result=bh.Open( "123" ) )
            Error();
      if( _kbhit() )
            { _getch(); return 1; }

      return 0;
}


////////////////////////////////////////////////////////
//  Main function - initialize, execute

void main(void)
{
      printf( "Initialization..." );
      Initialize();
      printf( " Done\n" );

      printf( "Executing - " );
      Execute();
      printf( " Done without interruption\n" );
}
```

4.3.2 RealTime Mode Example Program

The following program is an example that shows how to program the hand in RealTime mode using the C-Function Library. The code was generated using the BHControl Interface and compiled using Microsoft Visual C++ v6.0. This program will close finger one and starts closing finger two when finger one reaches position 5000. Finger three starts closing when finger two reaches position 5000. The program is terminated after six seconds.

```
////////////////////////////////////////////////////////
//                                                    //
//           Automatically Generated C++ Code         //
//           BHand Control Center Version 1.0         //
//                                                    //
//                   RealTime Mode                   //
//                                                    //
////////////////////////////////////////////////////////

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include "BHand.h"

BHand  bh;           // Handles all hand communication
int    value;        // Hand parameter obtained with Get
int    result;       // Return value (error) of all BHand calls


////////////////////////////////////////////////////////
// Error Handler - called whenever result!=0

void Error(void)
{
      printf("ERROR: %d\n%s\n", result, bh.ErrorMessage(result));
      exit(0);
}

////////////////////////////////////////////////////////
//  Initialize hand, set timeouts and baud rate

void Initialize(void)
{
      if(result=bh.InitSoftware(1,THREAD_PRIORITY_TIME_CRITICAL))
            Error();
      if( result=bh.ComSetTimeouts(0,100,15000,100,5000) )
            Error();
      if( result=bh.Baud(9600) )
            Error();
      if( result=bh.InitHand("") )
            Error();
}

////////////////////////////////////////////////////////
//  Set parameters, allocate data buffers, load files
```

```
void PrepareRealTime(void)
{
      // Set RealTime Flags to be sent during RealTime control
      if(result=bh.RTSetFlags("123", 1, 1, 0,  0, 1, 0, 1, 0, 1))
            Error();
}


////////////////////////////////////////////////////////
//  Run RealRime loop, return 1 if interrupted with a key

int RunRealTime(void)
{
      double var[4][3];
      int N=0, motor;
      DWORD  time, tmstart;
      bool terminate=false;

      // Start RealTime Mode
      bh.RTStart( "123" );

      // Start timer
      tmstart = GetTickCount();

      // Send RealTime control to hand
      bh.RTUpdate();

      printf( "Press Any Key to Abort..." );

      // Control Hand until termination
      while( !terminate && !_kbhit() )
      {
            time = GetTickCount() - tmstart;

            // Get RealTime Position and time
            for( motor=0; motor<4; motor++ )
            {
                  // Get motor position
                  var[motor][0] = bh.RTGetPosition( motor+'1' );
                  // Get time
                  var[motor][1] = (double)time;
                  // Get number of iterations
                  var[motor][2] = (double)N;
            }

            // Set F1 close velocity to 55
            value = (int)(55.00);
            bh.RTSetVelocity( '1', value );

            // If F1 position is > 5000 then set F2 close
            // velocity to 55, otherwise set to 0
            value=(int)(((var[0][0])>(5000.00))?(55.00):(0.00));
            bh.RTSetVelocity( '2', value );

            // If F2 position is > 5000 then set F3 close
            // velocity to 55, otherwise set to 0
            value=(int)(((var[1][0])>(5000.00))?(55.00):(0.00));
```

```
            bh.RTSetVelocity( '3', value );

            // If the time is greater than 6 seconds, then stop
                  // controlling hand in RealTime
            terminate = (0<(int)((var[0][1]) > (6000.00)));

            // Increment iterations
            N++;

            // Send all updated control parameters to the hand
            bh.RTUpdate();
      }

      // Exit RealTime mode
      bh.RTAbort();
      if( _kbhit() )
            { _getch(); return 1; }
      else
            return 0;
}

////////////////////////////////////////////////////////////
//  Main function - initialize, execute

void main(void)
{
      printf( "Initialization..." );
      Initialize();
      printf( " Done\n" );

      PrepareRealTime();

      printf( "RealTime Loop - " );
      if( RunRealTime() )
      {
            printf("Interrupted\n");
            return;
      }
      printf( " Done without interruption\n" );
}
```

5 Maintenance

5.1 Finger Cable Pretension

The second joint in each finger is driven by a brushless servo motor through a stainless steel cable that acts like a tendon transmitting torque from a pulley at the base of the finger out to a pulley at the second joint. If you have purchased the joint-torque sensor option, the tension in the tendon is used to determine the torque at the second joint.

Because low backlash and accurate torque measurements are desirable, you should periodically check that each tendon has the proper amount of pretension applied through Barrett Technology's patented cable tensioning mechanism. When the pretension becomes too loose, the fingertip will not be able to hold a secure position relative to its finger link. This looseness in cable tension allows movement of the fingertip with no movement of the motor. The torque sensor, if installed, will also exhibit hysteresis and will not follow the desired torque curves if the pretension is too low.

When the pretension becomes too loose, you should apply additional pretension by turning the tensioner screw, located on the back of each Joint 2 housing, clockwise with a 2-mm hex driver as shown in Figure 7.

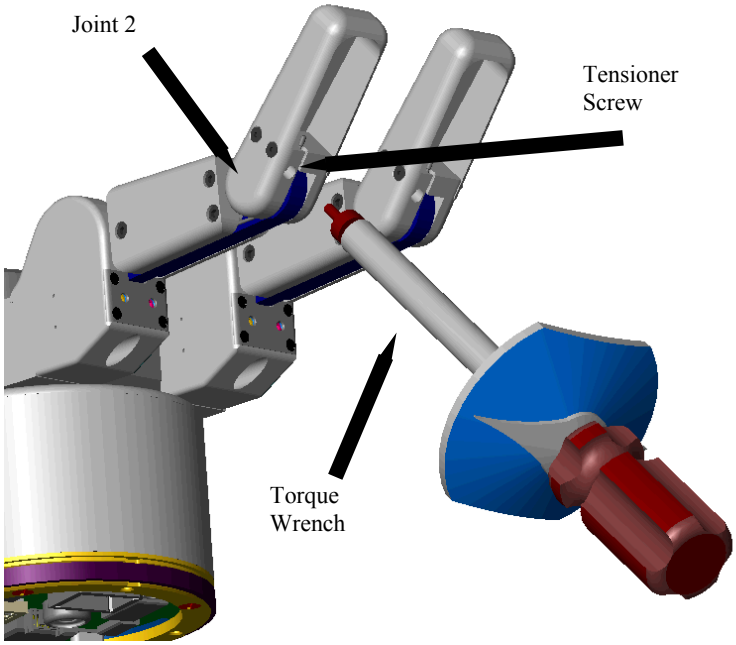


Figure 7 - Pretensioning the Tendon Cable

To increase the cable to the proper pretension, turn the 2-mm hex wrench clockwise until the applied torque reaches 15 in-oz. Barrett Technology suggests

using the supplied torque wrench with an adapter for the 2-mm hex wrench to assure proper pretension. The tendon is properly tensioned when all loose slack has been removed and you can feel the direct connection of the fingertip to its drive gears. DO NOT OVER-TIGHTEN THE TENDON! The pretensioning mechanism is stronger than the tendon and is capable of snapping it if over-tightened. Excessive pretension will change the frictional properties in the finger drives and may reduce the finger's range of motion.

5.2 Fastener Check

All screw fasteners in the BarrettHand have been installed with a thread locker, which should prevent loosening over the life of the product. However, after prolonged use, Barrett Technology recommends that you conduct a precautionary inspection to ensure all external fasteners are in place and tight. Ideally, this inspection should occur monthly under heavy use conditions.

Should any fasteners have become dislodged during operation, contact Barrett Technology for replacements or replacement specifications. Do not replace fasteners without contacting Barrett Technology as many fasteners have strict length specifications. Figure 8 shows some important fastener locations for inspection.

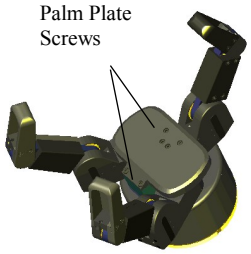


Figure 8 - Important Fastener Locations

5.3 Lubrication

Each BarrettHand unit has been lubricated and tested prior to shipping. Periodically, lubrication must be reapplied to areas with high probability of lubricant flow. Use the grease syringe to apply Mobil 1® Synthetic Grease (both included with the maintenance kit) to all exposed gear teeth at the application points according to Figure 9 and the schedule in Table 5.

Table 5 - Lubrication Schedule

Application Point	Maintenance Cycle
Finger Worm Gears	5000 cycles
Finger Spur Gears	5000 cycles
Finger Motor Spur Gears	5000 cycles
Palm Spur Gears	5000 cycles

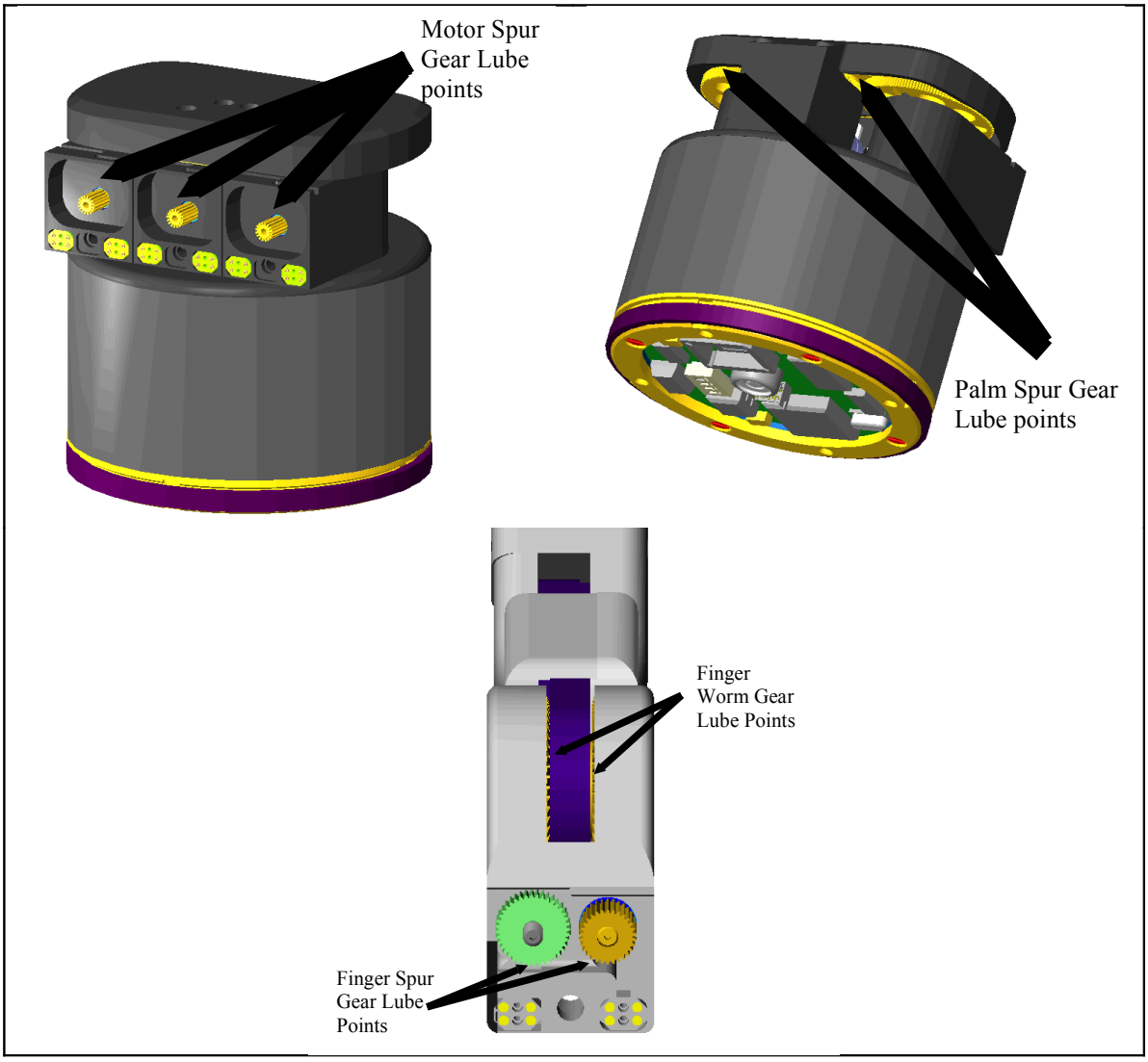


Figure 9 - Lubricant Application Points

Lubricating the finger spur gears requires caution, because you must remove each finger from the palm assembly to access this application point. Read all steps below before conducting this maintenance. It is best to lubricate only one finger at a time.

1. Open all fingers on the BarrettHand completely.

2. Shutdown the Power Supply and disconnect the BarrettHand Cable from the BarrettHand.

3. Locate and remove the finger attachment shoulder screw that holds the finger to its motor housing. The screw location is shown in Figure 10.

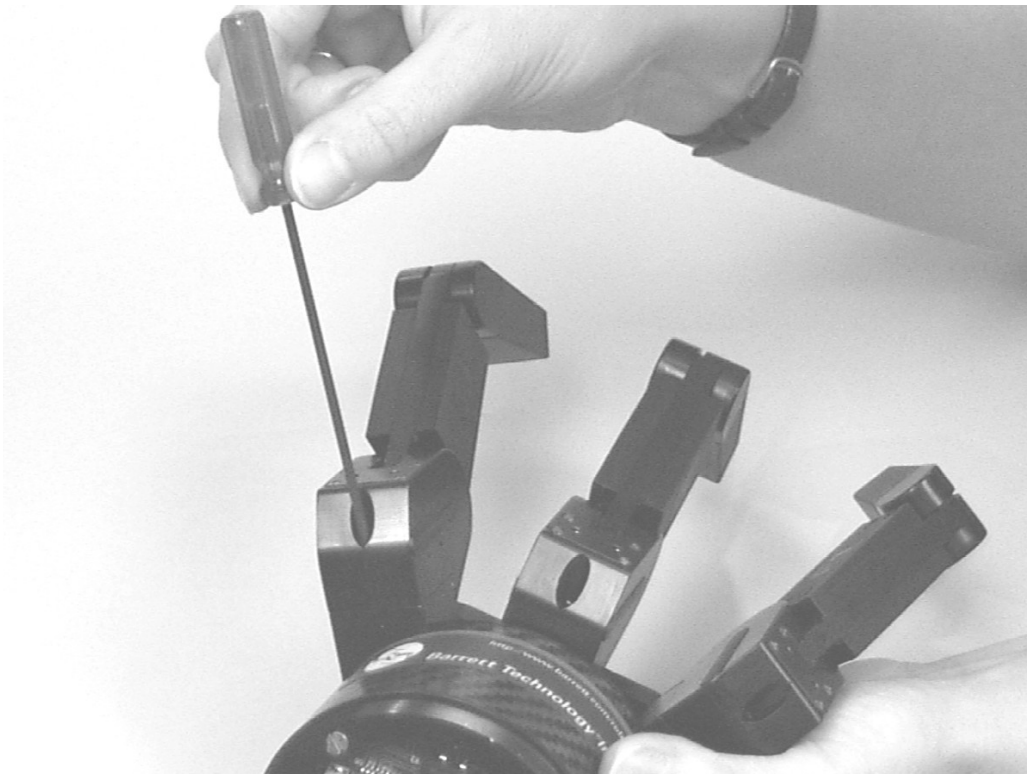


Figure 10 - Finger Attachment-Screw Location

4. Gently tilt the finger slightly forward and lift the alignment "teeth" out of their slots as shown in Figure 11. If the joint-torque sensor option is installed, BE CAREFUL not to damage the gold-plated electrical contact pins when disengaging the teeth.

5. Once the teeth are disengaged, move the finger away from its motor along a straight line perpendicular to the motor's face. Do not twist or rock the finger when removing or attaching it.

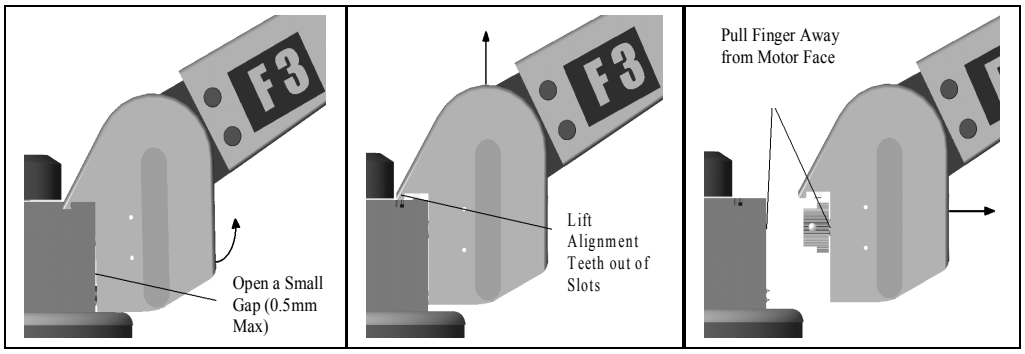


Figure 11 - Removing the Fingers for Maintenance

6. Make note of the relative position of the fingertip and inner finger link since removing the finger will disengage the coupling between them. Should either link, or the spur gears to which they are attached, move after the finger has been removed, the fingertip position must be reset. Use a 2-mm hex wrench to manually rotate the Joint-2 drive 6 1/2 revolutions from the position where both links are inline and horizontal.

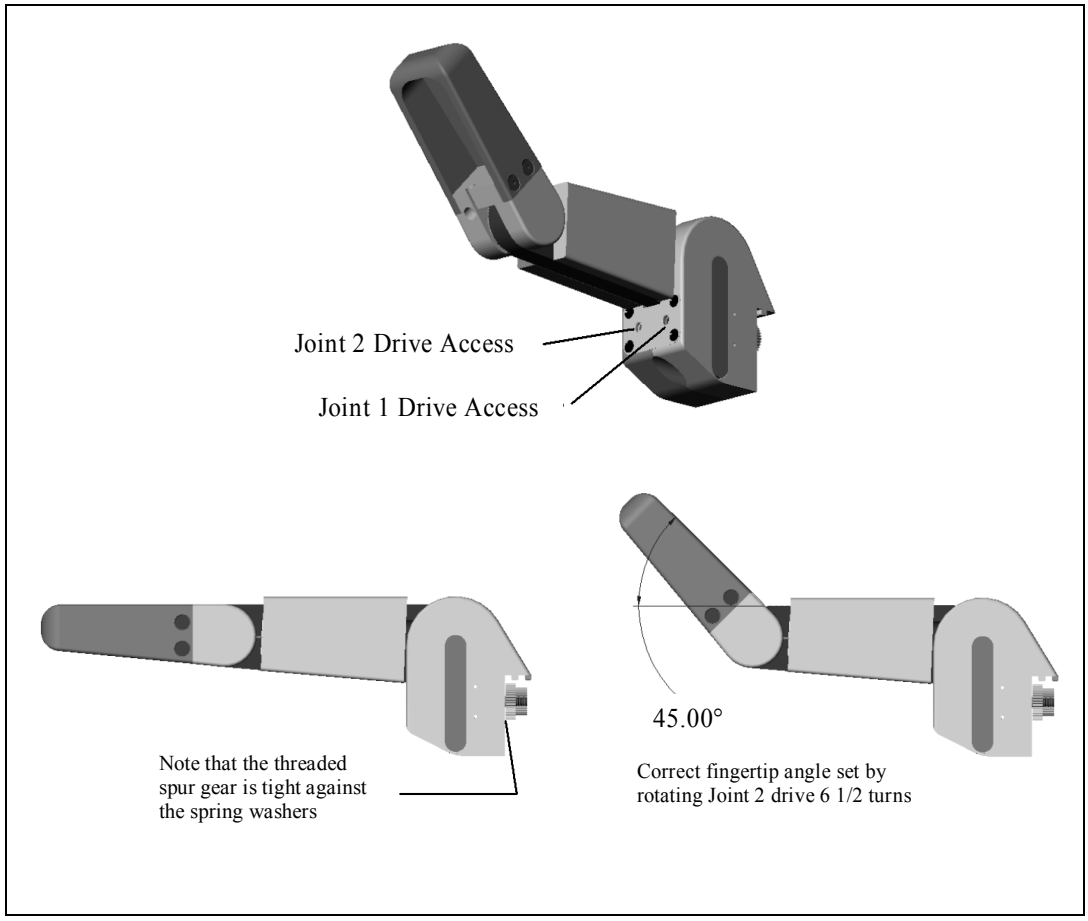


Figure 12 - Resetting the Fingertip Position after Finger Removal

7. Using the Mobil 1® Synthetic Grease syringe supplied with your maintenance kit, apply a generous amount of lubricant around the motor pinion cavity of the motor. Cover all gear teeth with a thick bead of grease. See Figure 9 for lubrication points.

8. Reset the fingertip position (see Step 5.3) and replace the finger onto its motor according to Figure 13, again taking great care not to damage the gold-contacts when seating the alignment teeth. The teeth must be fully seated into the alignment slots to ensure proper operation of the BarrettHand.

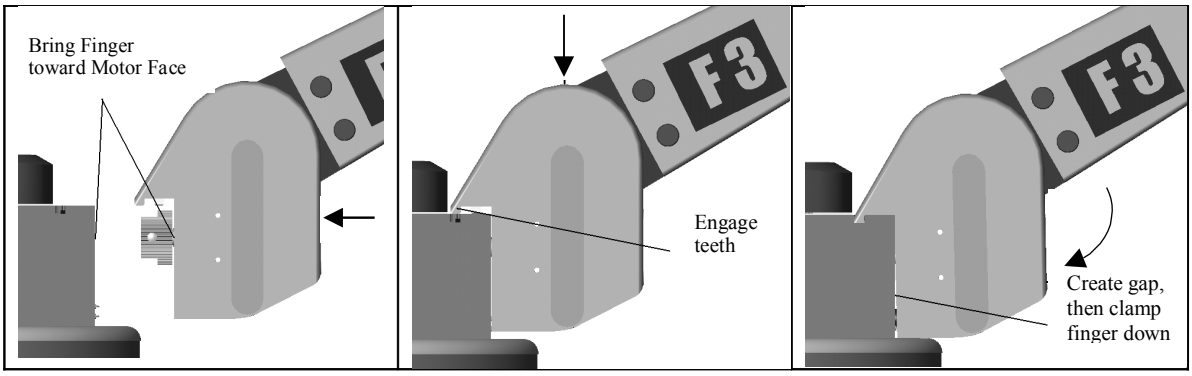


Figure 13 - Reattaching Fingers after Maintenance

9. Insert and tighten the finger attachment shoulder screw to retain the finger in place, as shown in Figure 10. Check the connection to the motor housing to be sure all gaps are closed.

5.4 Strain Gages

Due to variations in materials, manufacturing and external forces, the strain gage values may change. These changes will affect the zero force reading for each beam differently. To maintain consistent results, the zero force reading needs to remain constant. Each strain gage is equipped with a balancing potentiometer. Adjusting the balancing potentiometer will change the strain gage output for that finger. Adjust the balancing potentiometer until the no-load value is between 100 and 140. Use the following steps to zero the strain gages:

1. Initialize the BarrettHand.
2. Terminate the spread motor so it can be moved around the palm. (Issue the "T" command)
3. Remove the Shroud Cover screws shown in Figure 14. Some models of the BarrettHand will have four Shroud Cover screws. Remove the Shroud from the finger link.

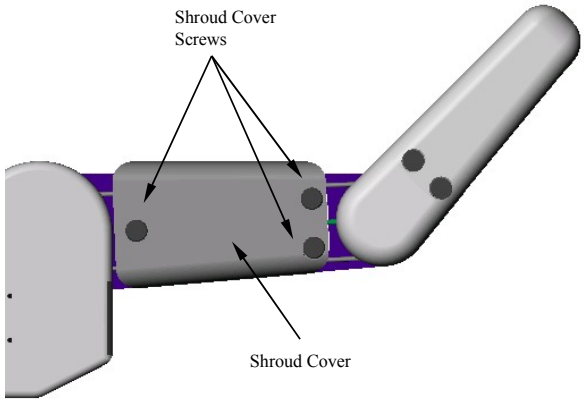


Figure 14 - Shroud Removal

4. Run the program *Monitor Strain.exe*. This program will continuously sample the strain gage values and print them to the screen.
5. Adjust the balancing potentiometer using a small flat head screwdriver until the desired value is reached. The balancing potentiometer requires very small adjustments, due its sensitivity. Apply as little pressure as possible on the balancing potentiometer during adjustment. See Figure 15.

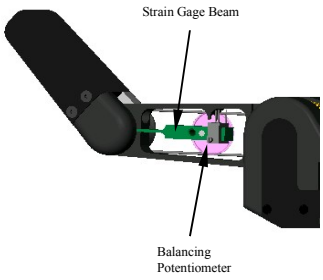


Figure 15 - Balancing Potentiometer

6. After balancing the strain gage, exit the *Monitor Strain.exe* program, put the shroud and shroud cover back on and secure the screws. Be careful not to touch the strain gage or damage any of the electrical wiring when replacing the shroud.

6 Troubleshooting

Symptom: The host computer will not communicate with the BarrettHand.

Possible Solution:
1. Verify all connections are secure to the Power Supply, BarrettHand and computer.
2. Verify the Power Supply is turned on.
3. Firmware may no longer be valid. Try downloading the firmware according to Section 3.5.
4. Host computer baud rate and BarrettHand baud rate may be set to different rates. Close the BHControl Interface and reset the BarrettHand, by pressing the red Reset button on the back of the Power Supply. Restart the BHControl Interface and try initializing again.
5. The communications port selected is being used by another program. Close all other programs that use the selected communications port. Reset the BarrettHand and restart the BHControl Interface.
6. If the problem persists, contact Barrett Technology.

Symptom: Firmware will not download onto BarrettHand.

Possible Solution:
1. Verify all connections are secure to the Power Supply, BarrettHand and computer.
2. Verify the Power Supply is turned on.
3. Reset the BarrettHand by pressing the red Reset switch on the back of the Power Supply and open a new session of the BHControl Interface.
4. Verify the dip switch on the BarrettHand CPU board, shown in Figure 16, are all set in the OFF position. The dip switch bank is located on the exposed circuit board under the threaded base ring of the BarrettHand. These switches are preset to the correct positions by the factory, but should be verified.
5. If the problem persists, contact Barrett Technology.

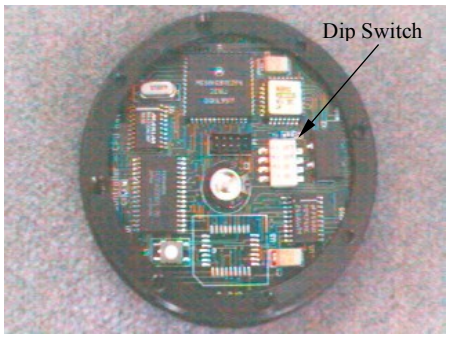


Figure 16 - Factory-Set Dip Switches

Symptom: Initial strain gage values do not fall within specified range.

Possible Solution:

1. The finger cable pretension is not adjusted properly. Refer to Section 5.1 for instructions on how to adjust.
2. The strain gage balancing potentiometer needs to be readjusted. Refer to Section 5.4 for instructions on how to adjust.
3. Verify the cable is riding on the idler pulley, see Figure 17.
4. Verify idler pulley rotates freely on the shoulder screw. The shoulder screw should not be tightened against the idler pulley. If so, contact Barrett Technology.
5. If the problem persists, contact Barrett Technology.

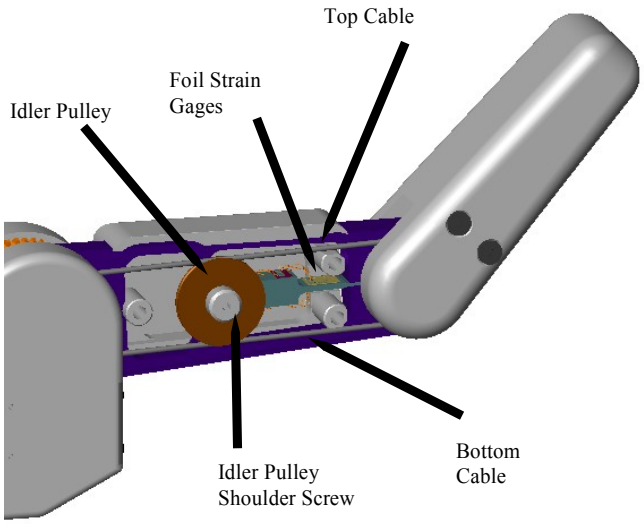


Figure 17 - Cable and Idler Pulley

Symptom: The strain gage values do not follow the expected strain gage curves, shown in Figure 24, while grasping.

Possible Solution:
1. The finger cable pretension is not adjusted properly. Refer to Section 5.1 for instructions on how to adjust.
2. The strain gage balancing potentiometer needs to be readjusted. Refer to Section 5.4 for instructions on how to adjust.
3. Verify the cable is riding on the idler pulley, see Figure 17.
4. Verify idler pulley rotates freely on the shoulder screw. The shoulder screw should not be tightened against the idler pulley. If so, loosen shoulder screw, shown in Figure 17, so the idler pulley will move with cable motion.
5. If the problem persists, contact Barrett Technology.

Symptom: Only the fingertip closes when the entire finger should close (Premature Breakaway).

Possible Solution:
1. Verify there is no object blocking the inner link from moving.
2. The finger was not opened with the minimum opening velocity of 40. Set the open velocity greater than or equal to 40. Initialize the finger having the problem. The finger should now close properly.
3. If the problem persists, contact Barrett Technology.

Symptom: Finger sticks fully closed.

Possible Solution:
1. Verify there are no objects or other fingers blocking the finger from opening completely.
2. The open velocity is too slow. Try increasing the open velocity to greater than or equal to 40 and opening the finger.
3. Verify the parameter MSG (Maximum Strain Gage) is greater than the strain gage value (SG). If the strain gages are not installed set MSG to 256.
4. The pretension in the cable is too high. Refer to Section 5.1 to set the finger cable pretension properly.
5. Set the open velocity greater than or equal to 40 and then initialize the finger.
6. If the problem persists, contact Barrett Technology.

Symptom: Finger sticks open.

Possible Solution:
1. Verify there are no objects or other fingers blocking the finger from closing.
2. The close velocity is to slow. Try increasing the close velocity to greater than or equal to 40 and closing the finger.
3. When the finger is moving the strain gage values exhibit noise that may be greater than the parameter MSG. Verify the parameter MSG (Maximum Strain Gage) is at least 50 greater than the strain gage value (SG). If the strain gages are not installed, set MSG to 256.
4. Set the close velocity to greater than or equal to 40 and then initialize the finger.
5. If the problem persists, contact Barrett Technology.

Symptom: Finger moves in opposite direction of commanded motion.

Possible Solution:
1. There is an encoder feedback problem. Reinitializing the finger should solve the immediate problem. It is likely this behavior will repeat in the future, contact Barrett Technology.

Symptom: The TorqueSwitch™ does not activate properly, prohibiting the fingertip from forming a complete grasp around an object.

Possible Solution:

1. The close velocity is too slow. Increase the close velocity greater than or equal to 40.
2. Reinitialize the finger, this may reset the TorqueSwitch™.
3. If the BarrettHand has been inactive for an extended period, the TorqueSwitch™ may need to be manually activated. Hold the inner link such that it will not move. Insert a 2-mm hex wrench into the Joint 2 Drive Access hole, seen in Figure 18, and turn clockwise. Continue to drive Joint 2 until the fingertip is moving and the inner link is stationary. Remove the 2-mm hex wrench and reinitialize the finger.
4. If the problem persists, contact Barrett Technology.

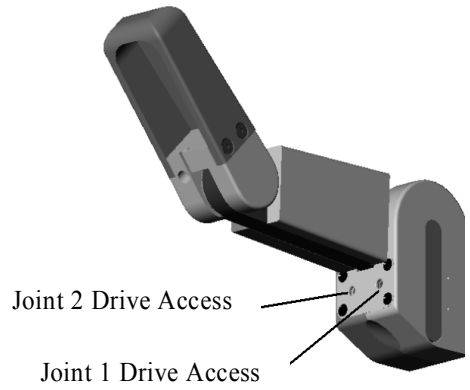


Figure 18 - Manual TorqueSwitch™ Activation

Symptom: The actual velocities of the fingers are different although the commanded velocities are the same.

Possible Solution:
1. Verify all of the finger velocity and filter parameters are the same (MCV, MOV, FPG, FDZ, FIP, ACCEL).
2. Each finger has slightly different friction due to manufacturing tolerances, resulting in different actual velocities for the same commanded velocity. Lubricating the high friction fingers will help reduce the friction and increase the velocity. See Section 5.3 for lubrication instructions.
3. The control algorithm used on the BarrettHand does not force the fingers to move at the same velocity, see Section 7.2. It is possible to move fingers at the same velocity, however it will require a more sophisticated control algorithm implemented in RealTime mode.
4. If the problem persists, contact Barrett Technology.

Symptom: Fingers will not close completely.

Possible Solution:
1. Verify there are no objects or other fingers blocking the finger from closing completely.
2. Verify the parameter MSG (Maximum Strain Gage) is greater than the strain gage value (SG). If the strain gages are not installed, set MSG to 256.
3. The pretension in the cable is too high. Refer to Section 5.1 to set the finger cable pretension properly
4. If the fingers were removed, the finger angle may be set incorrectly. Verify finger angle is correct by following the directions on disconnecting and reattaching fingers in Section 5.3
5. If the problem persists, contact Barrett Technology.

Symptom: The spread motion has excessive friction.

Possible Solution:
1. Lubricate the spread motor gears as shown in Section 5.3.
2. If the palm screws have been reinstalled, verify all screws are tightened with the same amount of torque. Excessive torque may cause spread friction.
3. If the problem persists, contact Barrett Technology.

Symptom: The threaded locking ring does not fit on the threaded base of the BarrettHand.

Possible Solution:
1. The threaded locking ring has been damaged or is warped. Contact Barrett Technology for a replacement part.
2. The threads on the base of the BarrettHand have been damaged. Contact Barrett Technology for service.

Symptom: The fingertip is easy to move and folds backwards.

Possible Solution:
1. The pretension in the cable is too low. Refer to Section 5.1 to set the finger cable pretension properly. If the problem persists, contact Barrett Technology.
2. The finger cable is broken. Verify this by removing the Shroud Cover, see Figure 19, and inspecting the cable. The cable should be intact and not broken. If the cable is broken, contact Barrett Technology.

Note: Some BarrettHand models may have 4 Shroud Cover Screws.

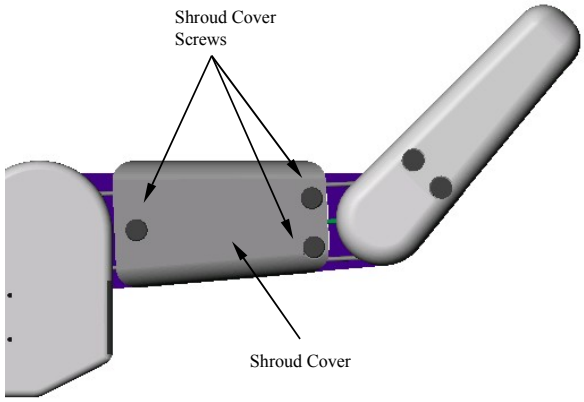


Figure 19 - Shroud Cover Removal

Symptom: The spread fingers F1 and F2 are at different angles around the palm.

Possible Solution:

1. An internal spread gear is damaged and will need to be replaced. Contact Barrett Technology.

7 Theory of Operation

7.1 Electronic Architecture

CPU Board

The CPU board handles all set-up, communications and high-level control of the power boards including coordinated motion, force monitoring, and motor speed monitoring. The main processor is a Motorola 68HC811E2FN microcontroller, which contains 256 bytes of RAM and 2Kbytes of EEPROM. The CPU board contains a 128 Kbytes RAM chip external to the microprocessor, which is used to store the BarrettHand firmware. The microcontroller operates at 1.25 MHz and communicates via standard RS-232C protocol at a factory-selected baud rate of 9600, no parity bits, eight bits per character and one stop bit. The BarrettHand is capable of communicating at rates up to 38.4K baud.

Motor Power Boards

Each power board handles current control of a single DC brushless motor in the BarrettHand using a Hewlett-Packard HCTL-1100 motion control chip. The optical incremental encoder signals from each motor, with 360 counts per motor revolution, are amplified and sent to the HCTL-1100 chip. The controller uses the encoder feedback for alignment at startup and for commutation of the motors via 10-20 kHz Pulse Width Modulation (PWM). It can also perform position and velocity control. A functional block diagram of the power board and its relation to other pieces of the control system is shown in Figure 20.

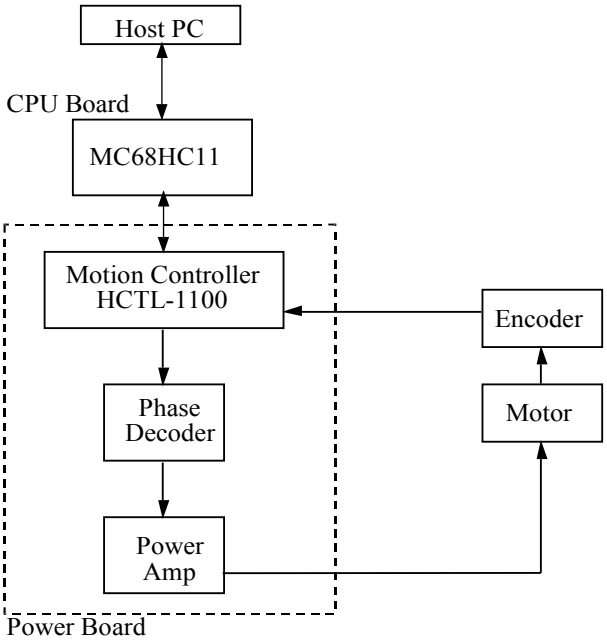


Figure 20 - BarrettHand Controller Block Diagram

Brushless Motors

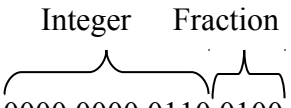
The BarrettHand utilizes one of the smallest DC brushless servo motors in the world for their torque range. Because the motors have no brushes, and thus less inherent friction, they achieve a better torque/mass ratio than typical brushed servos. There is also no need to replace worn brushes after the motors have been in service over a period of time. Table 6 shows BarrettHand motor properties.

Table 6 - BarrettHand Motor Properties

Number of Phases	3
Number of Poles	6
Rotor Magnets	Highest-Grade Samarium-Cobalt Rare-Earth
Commutation	Brushless Electronic PWM
Peak Torque	5 N-cm (8 oz-in)
Motor Constant	0.83 N-$\frac{cm}{\sqrt{W}}$ (1.17 $\frac{oz-in}{\sqrt{W}}$)
Position Feedback	360 counts/rev., incremental optical encoder

7.2 Motor Control

Two different types of methods are used for controlling individual motors in Supervisory mode, Velocity Control and Trapezoidal Profile Control. The Velocity Control is used during close and open commands (C and O). These commands use proportional gain and velocity error to control motors. The control velocity, in quadrature[2] counts per sample time, is 12 bits integer and 4 bits fraction. For example:



100 Control Velocity = 0000 0000 0110 0100 (Binary)
Integer = 0000 0000 0110 = 6
Fraction = 0100 = 4/16 = 0.25
100 Control Velocity = 6.25 quadrature counts / sample time

Use the following equation to determine velocity in revolutions per second:

$$V_q = V_R * N * t$$

Equation 1 - Velocity Conversion

[2] Encoder feedback from two channels allows four times the number of motor positions to actual lines on the encoder.

Where:
V_q is the velocity in quadrature counts / sample time
V_R is the velocity in revolutions / second
N is 4 * (Number of lines in the encoder) = 360 quadrature counts / revolution
t is the sample time on the hand electronics = 2.23E-4 seconds / sample time

Velocity Control uses proportional gain and velocity error to control the motor command, described in Equation 2. When the joint links contact an object or joint stop and have no movement for a pre-specified amount of time, stored in the TSTOP parameter, the motors will stop commanding a velocity.

$$MC_n = \left(\frac{K}{4}\right) * Y_n$$

Equation 2 - Velocity Control

Where:
MC_n is the motor command output.
K is the proportional gain stored in the variable FPG.
Y_n is (Command Velocity - Actual Velocity).

The second method of control is called Trapezoidal Profile Control and is used during move position commands (IO, IC and M). This mode moves the motor to the desired position and returns an error if the motor does not reach the position, within +/- the number of encoder counts stored in the parameter MPE. The following equation is used to determine the motor command:

$$MC_n = \left(\frac{K}{4}\right) X_n - \left[\left(\frac{A}{256}\right)\left(\frac{K}{4}\right) X_{n-1} + \left(\frac{B}{256}\right) MC_{n-1})\right]$$

Equation 3 - Trapezoidal Profile Control

Where:
MC_n is the motor command output.
K is the proportional gain stored in the variable FPG.
X_n is the position at time n.
A is the digital filter zero stored in the variable FDZ.
X_{n-1} is the position at time n -1.
B is the digital filter pole stored in the variable FIP.
MC_{n-1} is the motor command at time n -1.

The trapezoidal profile is determined by the acceleration and the maximum velocity set for the motor. Each motor has a corresponding acceleration stored in the variable ACCEL, 8 bits integer and 8 bits fraction. Use the same method for determining the actual acceleration as shown for the command velocity. The acceleration variable determines the rate of change of velocity until the maximum

velocity is reached. The default value for ACCEL is 1, or 0.0039 quadrature counts / (sample time)^2. The following equation can be used to determine the actual acceleration:

$$A_q = A_R * N * t^2$$

Equation 4 - Motor Acceleration

Where:
A_q is the acceleration in quadrature counts / (sample time)^2
A_R is the acceleration in revolutions / (second)^2
N is 4 * (Number of lines in the encoder) = 360
t is the sample time on the hand electronics = 2.23E-4 seconds / sample time

The maximum velocity, in quadrature counts / sample time, is determined by using part of the variables MCV and MOV, which are 12 bits integer and 4 bits fraction. The maximum velocity is set to the lower 8 bits of the 12 bit integer. For example:

Integer Fraction

200 Control Velocity = 0000 0000 1100 1000 (Binary)
Lower 8 bits of Integer = 0000 1100 = 12
Maximum Velocity = 12 quadrature counts / sample time

It is important to note the minimum velocity required to move the motors during Trapezoidal Profile Mode is 16.

7.3 Mechanisms

7.3.1 TorqueSwitch™

Barrett Technology's patented TorqueSwitch™ mechanism affords the BarrettHand unparalleled weight reduction without sacrificing dexterity or functionality by serving as a "smart" coupling of two finger joints to one motor. The mechanism's operation is similar to that of a simple screw fastener. Theoretically, the torque with which one tightens a uniform screw should be equal to that which is required to subsequently loosen it (neglecting inertia and provided all materials deformations remain elastic). This principle holds true for the TorqueSwitch™ mechanism.

The TorqueSwitch™ consists of a threaded shaft, a pair of Belleville spring washers and a spur gear with a threaded bore, shown in Figure 21.

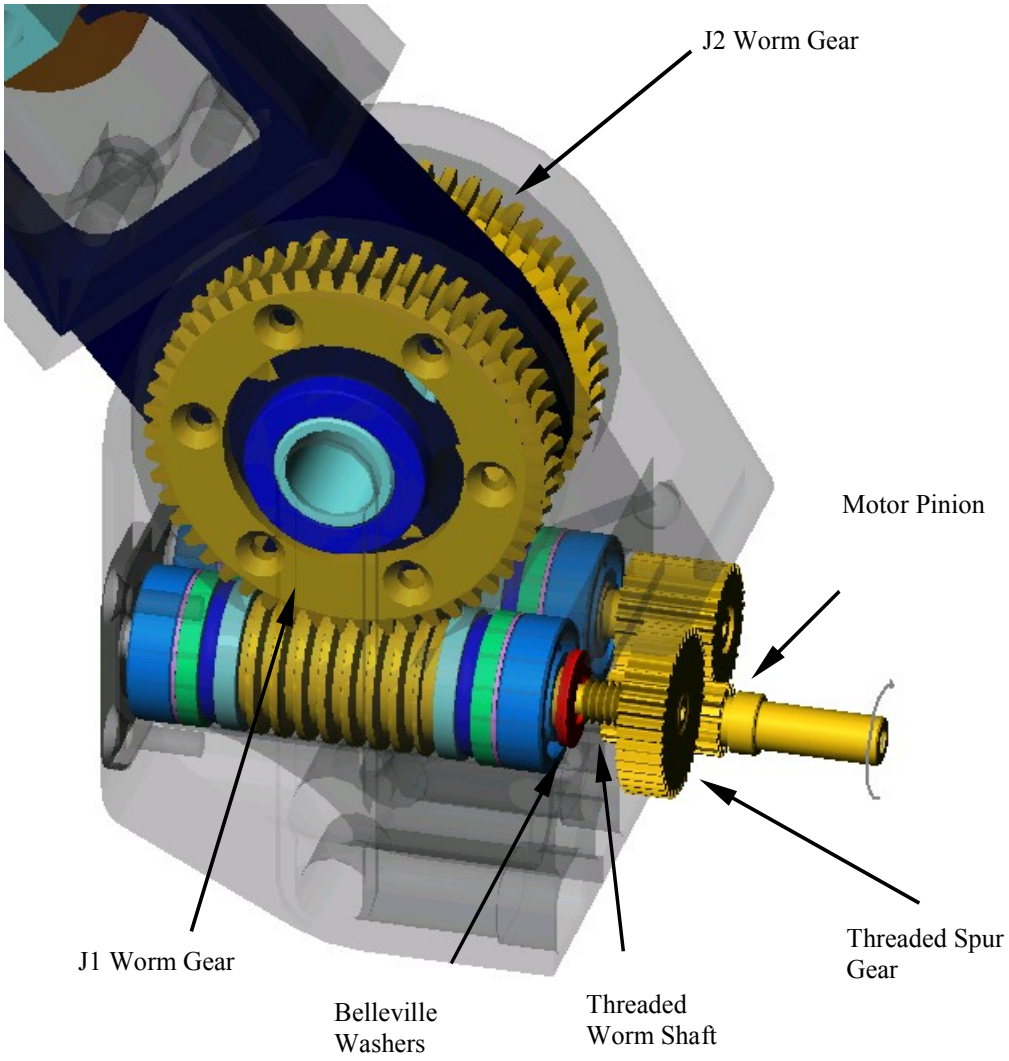


Figure 21 - Barrett's Patented TorqueSwitch™ Mechanism

The following description follows the progression of Figure 22. When the clutch is engaged, both worm gear drives and their corresponding finger links are coupled to the geared servo-motor pinion. In this state, the ratios of motor position to joint position for the 1st and 2nd finger joints are 93.75:1 and 125:1, respectively.

When a finger opens against its motion stop, the threaded spur gear is tightened against the Belleville spring washers with a known motor torque; thereby setting the threshold torque for disengaging the spur gear. If the inner finger link, while closing, contacts a target object of sufficient stiffness to increase the torque in the gear train above the threshold torque, the clutch will disengage from the Belleville spring washers.

When the clutch is disengaged, the threaded spur gear “free-wheels” on the threaded shaft, allowing the motor pinion to turn without inducing motion in the inner link. Instead, only the smaller spur gear, solidly fixed to its shaft, is driven. This fixed spur gear actuates the worm gear drive for the fingertip. Thus, when the clutch is disengaged, the inner finger link remains motionless while the fingertip continues to move allowing the fingers to form-fit around any shape.

The minimum finger open velocity needed to reset the TorqueSwitch™ is 40. Barrett Technology does not guarantee proper operation of the TorqueSwitch™ unless the open velocity is at least 40. If a slower velocity is used, the finger may exhibit premature breakaway, characterized by only the fingertip closing during a finger close command.

Figure 22 shows the sequence of events occurring when the clutch is utilized.

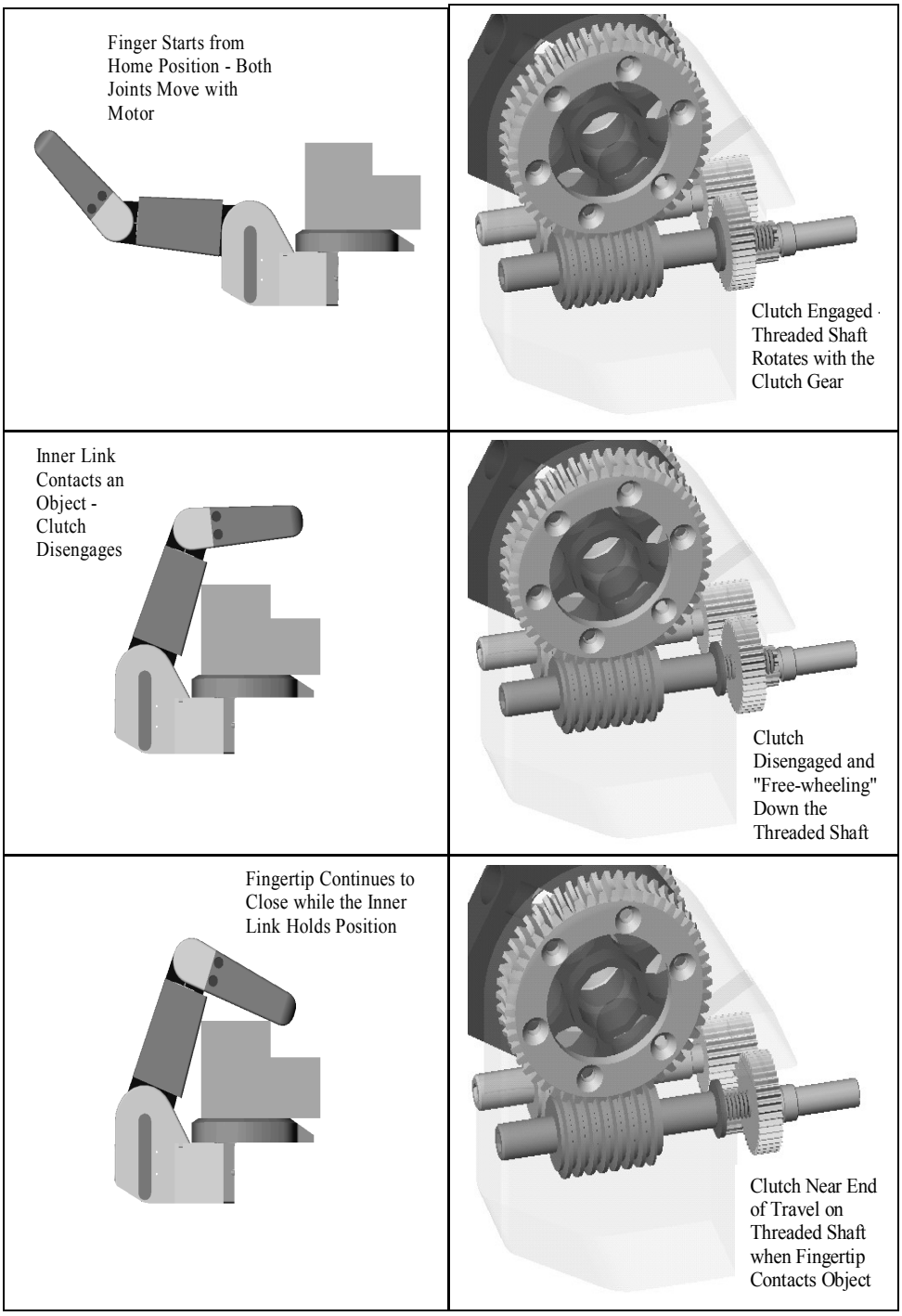


Figure 22 - TorqueSwitch™ Operation

7.3.2 Spread Motion

The spreading action of fingers F1 and F2 on the BarrettHand increases the dexterity of the entire unit with only one additional actuator. Optimal grasp configurations can be achieved "on-the-fly" without costly tool changes

associated with traditional grippers. In addition, the backdrivability built into this degree of freedom causes the BarrettHand's grasp shape to change in mid-grasp, creating a more stable grasp of oddly shaped target objects.

Should you wish to control the spread position of the fingers, the complete command set available to the fingers is also available for the spread, including commands for fixed-increment motion and move-to-position commands.

7.4 Optional Strain Gage Joint-Torque Sensor

The BarrettHand provides an optional Joint-Torque sensor for each finger. The Joint-Torque sensor measures the torque about the outer joint on each finger, see Figure 23. The Joint-Torque sensor is comprised of a flexible beam with four foil strain gages applied and wired in a Wheatstone Bridge configuration. When a force is applied to the fingertip, Force A, the torque is measured by the amount of deflection in the beam. The beam deflection is proportional to the difference in cable tension, which translates to a force on the pulley attached to the flexible beam, Force B. The flexing in the beam creates a measurable voltage change in the Wheatstone Bridge. This difference in voltage is conditioned, amplified, converted and available to you in digital form.

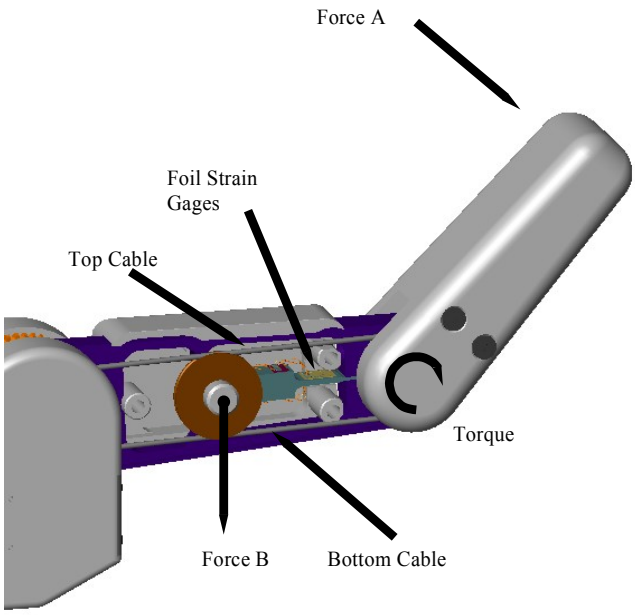


Figure 23 - Strain Gage Joint-Torque Sensor

The gages are adjusted before leaving the factory and should exhibit a no-load value between 100 and 140. If the gage values do not fall within the specified range see Section 5.4.

Applying a force at a distance perpendicular to the fingertip will produce a torque about Joint 2, see Figure 23. Use the BHControl Interface to determine digital torque values. If the torque curve measured does not approximate the torque curve shown in Figure 24, see Section 6. The torque curves for each finger will be different due to the variations in materials.

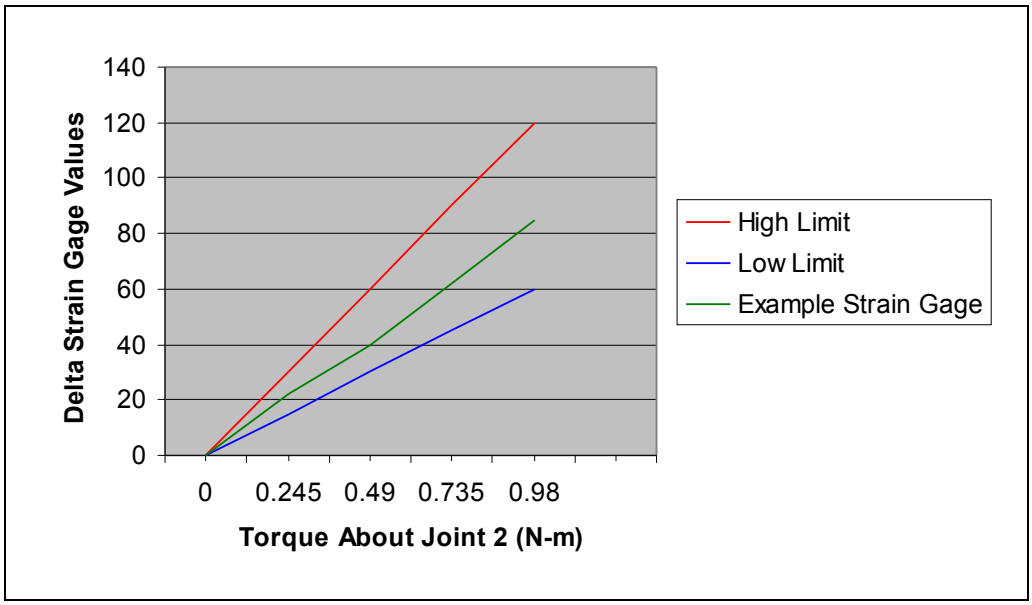


Figure 24 - Strain Gage Torque Curves

Note: Barrett Technology uses a digital force gage to apply the force perpendicular to the fingertip. The force is then converted to a torque.

7.5 Kinematics

The kinematics for the BarrettHand were determined using the Denavit - Hartenberg notation described in "Introduction to Robotics, Mechanics and Control 2nd Edition", John J. Craig. Each finger is considered its own manipulator and is referenced to a world coordinate frame in the center of the palm. Use the forward kinematics calculated in this section to determine fingertip position and orientation with respect to the palm.

The following homogeneous transform equation is used to determine the transforms between axes k and k-1.

$$ {}^{k-1}\mathbf{T}_k = \begin{bmatrix} \mathrm{c}\theta_{\mathrm{k}} & -\mathrm{s}\theta_{\mathrm{k}} & 0 & \mathrm{a}_{\mathrm{k-1}} \\ \mathrm{s}\theta_{\mathrm{k}} c\alpha_{k-1} & \mathrm{c}\theta_{\mathrm{k}} c\alpha_{k-1} & -s\alpha_{k-1} & -\mathrm{s}\alpha_{k-1} d_k \\ \mathrm{s}\theta_{\mathrm{k}} s\alpha_{k-1} & \mathrm{c}\theta_{\mathrm{k}} s\alpha_{k-1} & c\alpha_{k-1} & \mathrm{c}\alpha_{k-1} d_k \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Equation 5 - Homogeneous Transform Between {k-1} and {k}

Where:

a_{k-1} = distance from z_{k-1} to z_k measured along x_{k-1}
α_{k-1} = angle between z_{k-1} to z_k measured about x_{k-1}
d_k = distance from x_{k-1} to x_k measured along z_k
θ_k = angle between x_{k-1} to x_k measured about z_k

$$ c\theta_k = \cos(\theta_k) $$
$$ s\theta_k = \sin(\theta_k) $$

The forward kinematics are determined using the following equation:

$$ {}^{w}\mathbf{T}_T = {}^{w}\mathbf{T}_0 \, {}^{0}\mathbf{T}_1 \, {}^{1}\mathbf{T}_2 \, {}^{2}\mathbf{T}_3 \, {}^{3}\mathbf{T}_T $$

Equation 6 - Forward Kinematics from Fingertip to World

Table 7 is a list of the parameters used to determine the kinematics for each of the fingers. These parameters are found in each of the forward kinematics equations.

Table 7 - D-H Parameter Values for all Fingers

Parameter	Value
A_1	50mm
A_2	70mm
A_3	50mm
D_0	25mm
D_3	9.5mm
Φ_2	2.46°
Φ_3	50°

To calculate the joint angle, *before* the TorqueSwitch™ has been activated, based on the motor angle use Equation 7:

$$\begin{bmatrix} \Theta_{J11} \\ \Theta_{J12} \\ \Theta_{J21} \\ \Theta_{J22} \\ \Theta_{J31} \\ \Theta_{J32} \\ \Theta_{J41} \\ \Theta_{J42} \end{bmatrix} = \begin{bmatrix} .008 & 0 & 0 & 0 \\ .0027 & 0 & 0 & 0 \\ 0 & .008 & 0 & 0 \\ 0 & .0027 & 0 & 0 \\ 0 & 0 & .008 & 0 \\ 0 & 0 & .0027 & 0 \\ 0 & 0 & 0 & .0571 \\ 0 & 0 & 0 & .0571 \end{bmatrix} \begin{bmatrix} \Theta_{M1} \\ \Theta_{M2} \\ \Theta_{M3} \\ \Theta_{M4} \end{bmatrix}$$

Equation 7 - Motor to Joint Angle Transform before TorqueSwitch™ Activation

After the TorqueSwitch™ has been activated the inner link stops moving and all the joint torque is applied to the outer link. The joint angle, *after* the TorqueSwitch™ has been activated, based on the motor angle can be determined using Equation 8. See 7.6 for information on how to detect TorqueSwitch™ activation.

$$\begin{bmatrix} \Theta_{J11} \\ \Theta_{J12} \\ \Theta_{J21} \\ \Theta_{J22} \\ \Theta_{J31} \\ \Theta_{J32} \\ \Theta_{J41} \\ \Theta_{J42} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ .0107 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & .0107 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & .0107 & 0 \\ 0 & 0 & 0 & .0571 \\ 0 & 0 & 0 & .0571 \end{bmatrix} \begin{bmatrix} \Theta_{M1} \\ \Theta_{M2} \\ \Theta_{M3} \\ \Theta_{M4} \end{bmatrix}$$

Equation 8 - Motor to Joint Angle Transform after TorqueSwitch™ Activation

Equation 8 is only valid for the continuous movement through TorqueSwitch™ activation. Once the finger stops, the end tip position cannot be accurately determined until the TorqueSwitch™ mechanism is reset. Reset the TorqueSwitch™ by opening the finger against its open stop with a minimum speed of 40.

Note: The feedback device for each of the motors uses a 90 line, or 360 count, encoder. Thus, the motor angle *is* the encoder position.

All of the kinematics for the BarrettHand are derived from the zero position. The zero position of the BarrettHand is shown in Figure 25

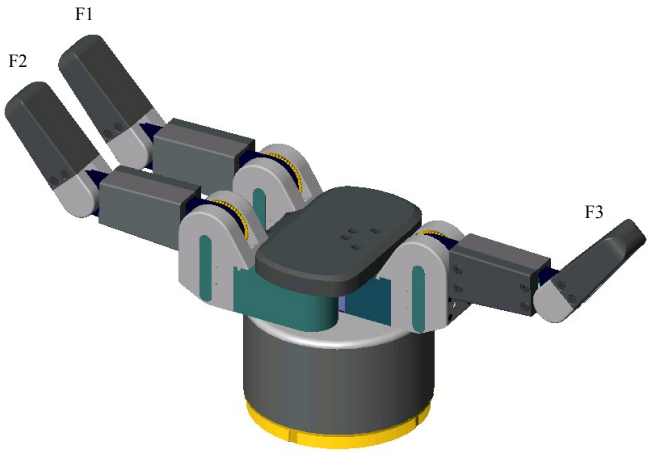


Figure 25 - BarrettHand in Zero Position

Finger F1 Kinematics:

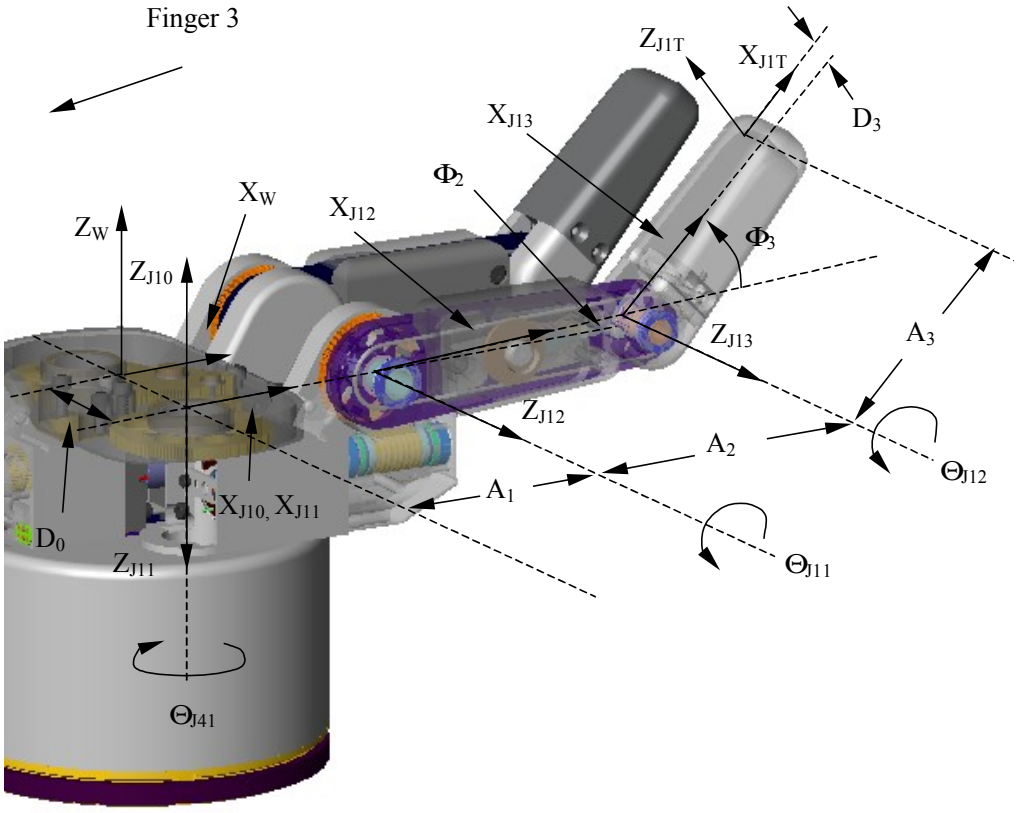


Figure 26 - D-H Frame Assignment for Finger F1

Table 8 - D-H Link Parameters for Finger F1

Joint	a_{k-1}	α_{k-1}	d_k	θ_k
1	0	π	0	Θ_{J41}
2	A_1	$-\pi/2$	0	$\Theta_{J11}+\Phi_2$
3	A_2	0	0	$\Theta_{J12}+\Phi_3$
T	A_3	$-\pi/2$	D_3	0

The relationship between frame 0 and the *world* coordinate frame is determined by using:

$$ {}^{w}_{0}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -D_0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The transforms from each axis to its previous axis can be determined using the homogeneous transform in Equation 5 and the link parameters for finger F1 in Table 8.

Using Equation 6, the forward kinematics were determined to be:

$$ {}^{w}_{T}T = \begin{bmatrix} c_4 c_{ab} & s_4 & -c_4 s_{ab} & A_3 c_4 c_{ab} + D_3(-c_4 s_{ab}) + A_2 c_4 c_a + A_1 c_4 \\ -s_4 c_{ab} & c_4 & s_4 s_{ab} & A_3(-s_4 c_{ab}) + D_3 s_4 s_{ab} - A_2 s_4 c_a - A_1 s_4 - D_0 \\ s_{ab} & 0 & c_{ab} & A_3 s_{ab} + D_3 c_{ab} + A_2 s_a \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Equation 9 - Forward Kinematics for Finger F1

Where:

$$ a = \Theta_{J11} + \Phi_2 $$
$$ b = \Theta_{J12} + \Phi_3 $$
$$ c_{ab} = \cos(a+b) $$
$$ s_{ab} = \sin(a+b) $$
$$ c_4 = \cos(\Theta_{J41}) $$
$$ s_4 = \sin(\Theta_{J41}) $$

Use Equation 9 and the values in Table 7 to determine finger F1's end tip position.

Finger F2 Kinematics:

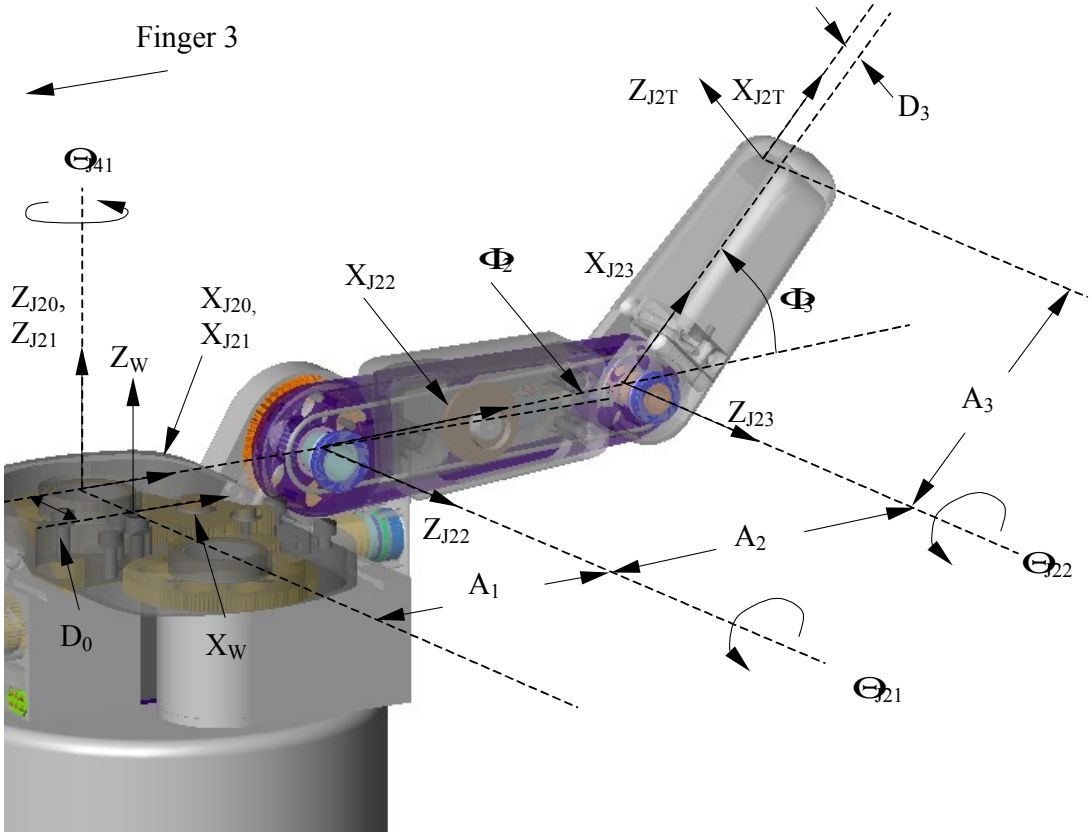


Figure 27 - D-H Frame Assignment for Finger F2

Table 9 - D-H Link Parameters for Finger F2

Joint	a_{k-1}	α_{k-1}	d_k	θ_k
1	0	0	0	Θ_{J41}
2	A_1	$\pi/2$	0	$\Theta_{J21}+\Phi_2$
3	A_2	0	0	$\Theta_{J22}+\Phi_3$
T	A_3	$-\pi/2$	D_3	0

The relationship between frame 0 and the *world* coordinate frame is determined by using:

$$ {}^{w}_{0}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & D_0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The transforms from each axis to its previous axis can be determined using the homogeneous transform in Equation 5 and the link parameters for finger F2 in Table 9.

Using Equation 6, the forward kinematics were determined to be:

$$ {}^{w}_{T}T = \begin{bmatrix} c_4 c_{ab} & -s_4 & -c_4 s_{ab} & A_3 c_4 c_{ab} + D_3(-c_4 s_{ab}) + A_2 c_4 c_a + A_1 c_4 \\ s_4 c_{ab} & c_4 & -s_4 s_{ab} & A_3 s_4 c_{ab} + D_3(-s_4 s_{ab}) + A_2 s_4 c_a + A_1 s_4 + D_0 \\ s_{ab} & 0 & c_{ab} & A_3 s_{ab} + D_3 c_{ab} + A_2 s_a \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Equation 10 - Forward Kinematics for Finger F2

Where:

$$ a = \Theta_{J21} + \Phi_2 $$
$$ b = \Theta_{J22} + \Phi_3 $$
$$ c_{ab} = \cos(a+b) $$
$$ s_{ab} = \sin(a+b) $$
$$ c_4 = \cos(\Theta_{J41}) $$
$$ s_4 = \sin(\Theta_{J41}) $$

Use Equation 10 and the values in Table 7 to determine finger F2's end tip position.

Finger F3 Kinematics:

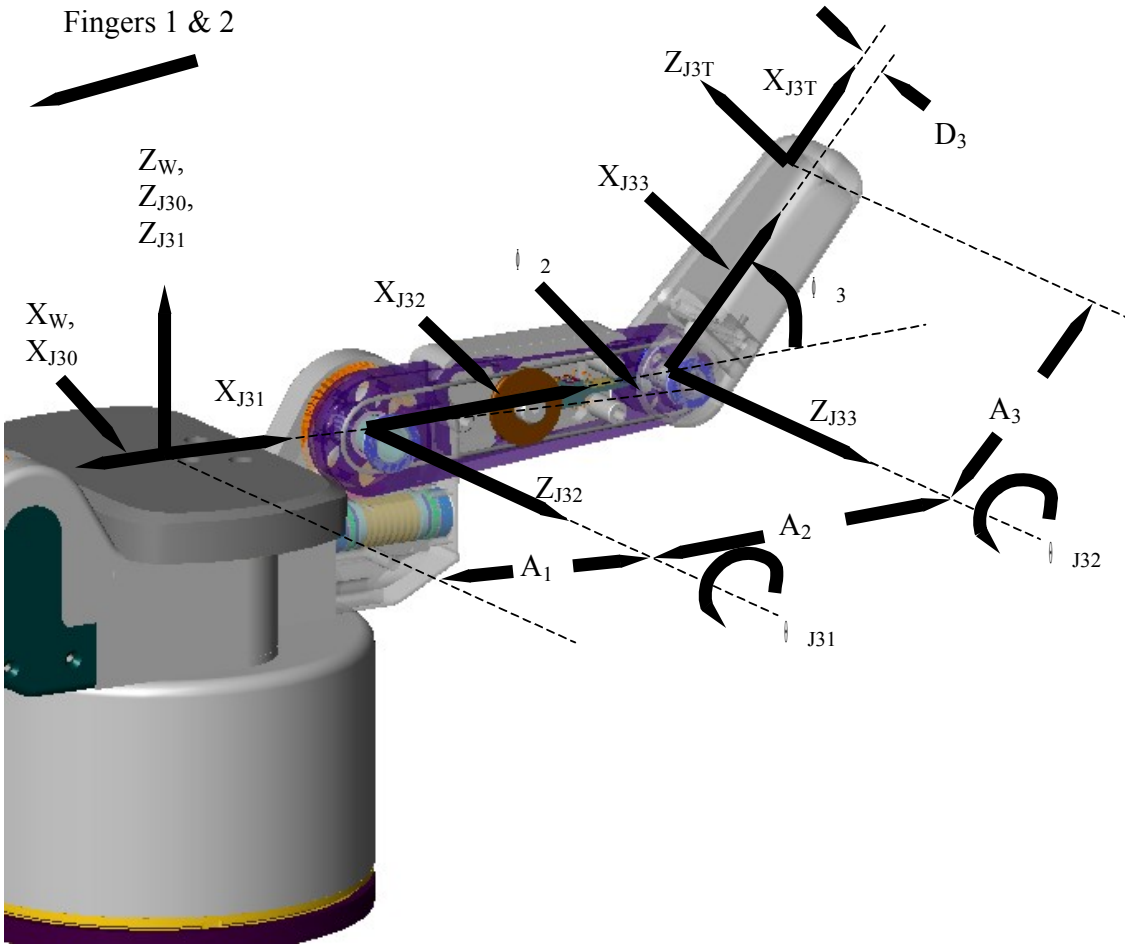


Figure 28 - D-H Frame Assignment for Finger F3

Note: The spread motion, Θ_{J41}, only affects motions for fingers F1 and F2. Therefore, we added an extra frame for finger F3 for consistency between all finger joint variables.

Table 10 - D-H Link Parameters for Finger F3

Joint	a_{k-1}	α_{k-1}	d_k	θ_k
1	0	0	0	π
2	A_1	$\pi/2$	0	$\Theta_{J31}+\Phi_2$
3	A_2	0	0	$\Theta_{J32}+\Phi_3$
T	A_3	$-\pi/2$	D_3	0

The relationship between frame 0 and the *world* coordinate frame is determined by using:

$$ {}^{w}_{0}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The transforms from each axis to its previous axis can be determined using the homogeneous transform in Equation 5 and the link parameters for finger F3 in Table 10.

Using Equation 6, the forward kinematics were determined to be:

$$ {}^{w}_{T}T = \begin{bmatrix} -c_{ab} & 0 & s_{ab} & -A_3 c_{ab} + D_3 s_{ab} - A_2 c_a - A_1 \\ 0 & 1 & 0 & 0 \\ s_{ab} & 0 & c_{ab} & A_3 s_{ab} + D_3 c_{ab} + A_2 s_a \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Equation 11 - Forward Kinematics for Finger F3

Where:

$$ a = \Theta_{J31} + \Phi_2 $$
$$ b = \Theta_{J32} + \Phi_3 $$
$$ c_{ab} = \cos(a+b) $$
$$ s_{ab} = \sin(a+b) $$

Use Equation 11 and the values in Table 7 to determine finger F3's end tip position.

7.6 Joint Motion Limits

The maximum joint motion limits for the BarrettHand are calculated based on the zero position seen in Figure 25. Depending on the position of the spread joint, Θ_{J41}, and the objects in the grasp, the maximum joint motion limits for the finger links may vary.

The inner link, Θ_{J11}, Θ_{J21}, Θ_{J31}, has a maximum joint motion limit of 140° with no object blocking movement and Θ_{J41} in the full close or open position. The outer link, Θ_{J12}, Θ_{J22}, Θ_{J32}, has a maximum joint motion limit of 45° when Θ_{J41} is fully open or closed and there is no object in the grasp, as shown in Figure 29. When the spread is in any position other than full open or close, the fingers may not have the full range of motion due to interference with other fingers.

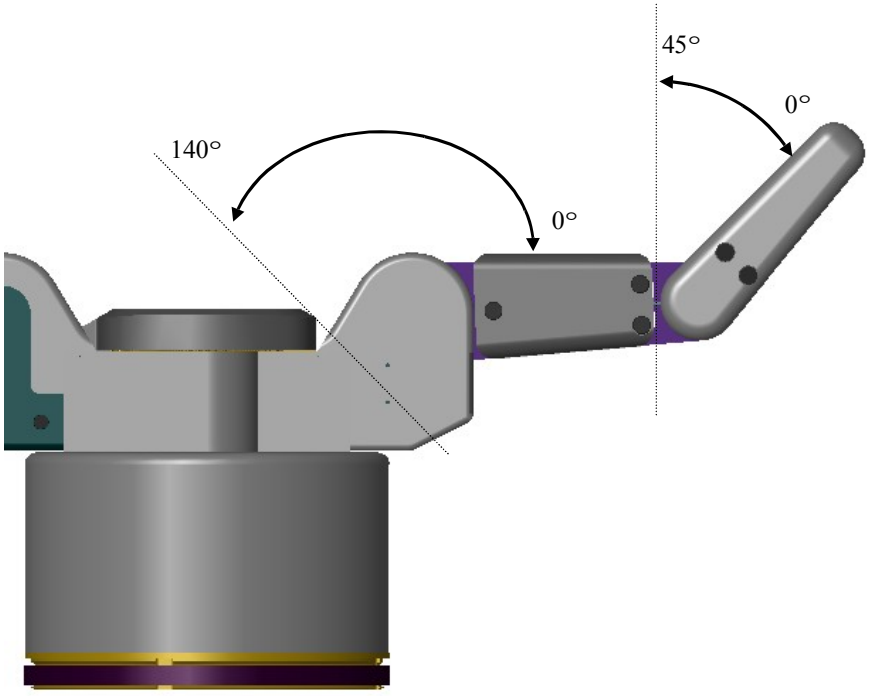


Figure 29 - Finger Joint motion limit Range

The spread joint, Θ_{J41}, has a maximum joint motion limit of 180° with no object blocking movement and all fingers in the full open position. If the fingers are partially closed or there is an object in the grasp, Θ_{J41} may not close completely due to finger interference. See Figure 30.

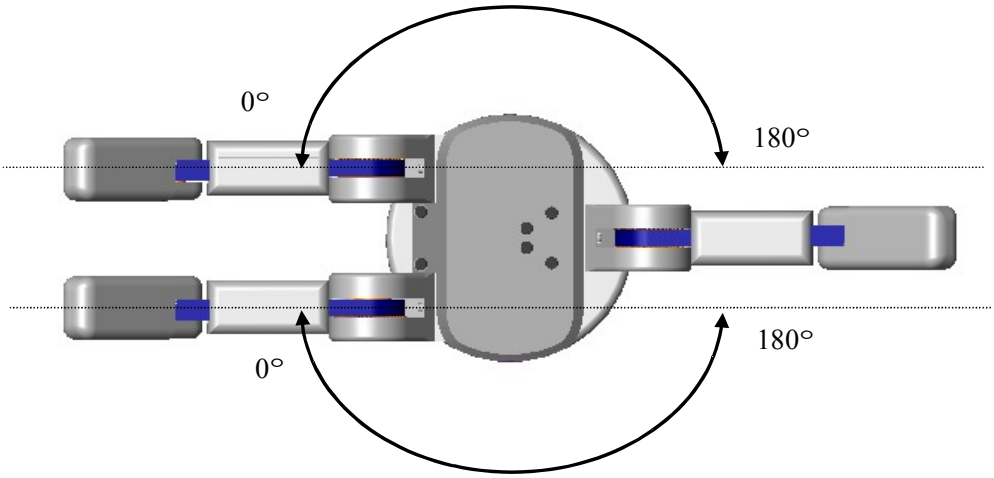


Figure 30 - Spread Joint motion limit Range

Appendix A Technical Specifications

Kinematics	Qty.
Total fingers:	3
Fingers which spread:	2
Joints per finger:	2
Motors per finger:	1
Axes of spread motion:	2
Motors for spread motion:	1
Total axes:	8
Total motors:	4

Range of Motion

Finger base joint:	140°
Fingertip:	45°
Finger spread:	180°

Finger Speed

Finger fully open to fully closed:	1.0 sec
Full 180° finger spread:	0.3 sec

Position Sensing

Type: optical incremental encoder
Resolution: 0.008° at the finger base joint
17,500 encoder counts full finger open to full close

Weight

BarrettHand:	1.18 kg (2.60 lb.)
Optional Arm Adapter B0133:	0.2 kg (0.4 lb.) additional

Payload

2.0 kg (4.4 lb.) per finger at tip

Motor Type

Samarium-Cobalt, brushless, DC, servo motors

Mechanisms

Worm drives integrated with patented cable drive and TorqueSwitch™

Power Requirements

Single phase AC electrical outlet with ground.
Load: 500 W
Phases: Single
Voltage: 120/240 ±10% VAC
Frequency: 50/60 Hz

Power Supply
Location: dry, stationary surface
Size H,W,D: 200 x 200 x 300 mm (7.5 x 7.5 x 12 in)
Weight: 5 kg (11 lb.)

Cables
3 meter continuous-flex cable, 8mm diameter (BarrettHand Cable)
3meter serial cable
AC line cord

Dimensions

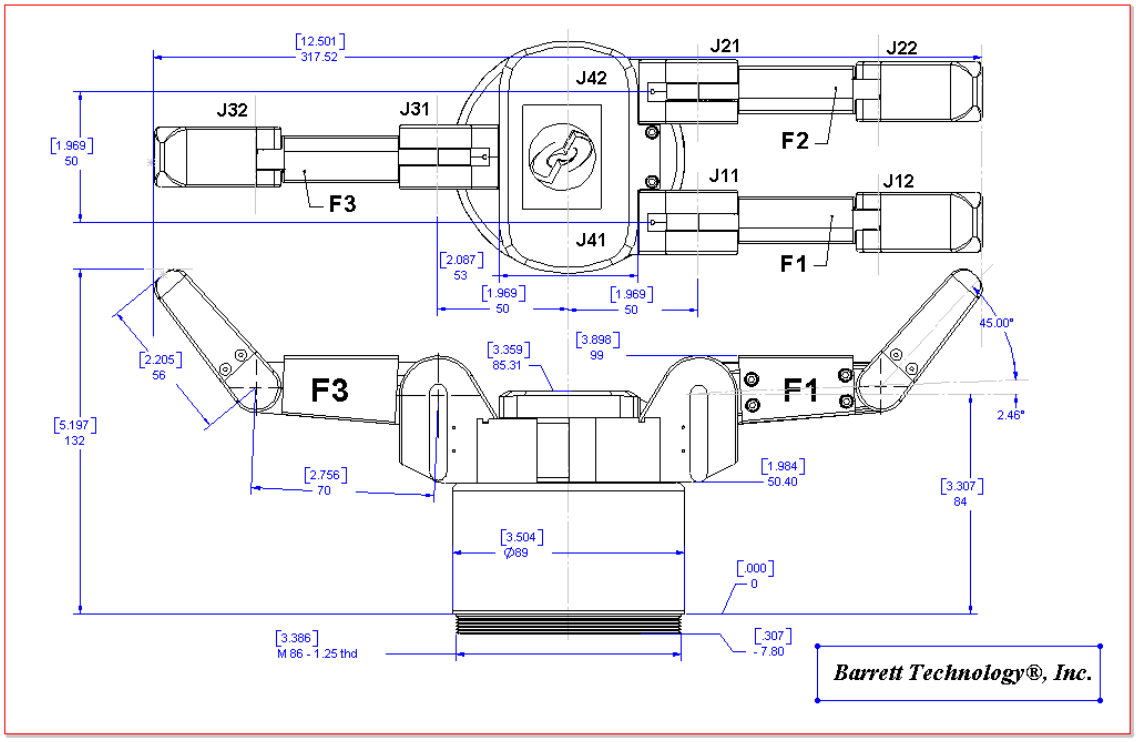


Figure 31 - BarrettHand Dimensions

Available Options
B029A Strain gage Fingertip Torque Sensors for all three fingers
B0133 Arm Adapter (with custom bolt circle)
B0111 C-Function Library
B01C3 Subscription Service

US Patents
5501498
5388480
4957320

Appendix B FAQ

Q1: What type of finger motions are possible with the BarrettHand and what servos and mechanisms are used to control them?

A1: The BarrettHand has 3 identical curling 2-joint fingers, each with its own built-in, independent, high-performance brushless motor drive. A patented TorqueSwitch™ mechanism then channels torque from the motor to the two joints depending on:

1. The TorqueSwitch™ level set for that particular grasp and
2. The joint-torque status.

In its full-open state, each finger's inner-link surface is almost parallel with the palm plate, while the outer finger link is curled inward by 45 degrees. When a finger is commanded to close under velocity or position control, the links move according to the transforms in Equation 7, the resulting motion will be curling, to promote form closure before a grasp contact is initiated. If the outer fingertip makes first contact with an object, it develops full force against the object until no motion is detected, at which point the motor current may be removed since the finger joints become mechanically locked. However, if the inner finger link makes first contact, the motor applies the torque to both links until the TorqueSwitch™ level is reached. At this instant, the inner link is locked into position mechanically, and all motor torque is shunted to the outer link, which stops only at motor stall torque. The net result is highly effective grasping.

The patented finger-spread motion has two opposable fingers and one fixed finger. To minimize the number of motors (and thereby the weight, bulk, heat, power, and cost of the BarrettHand), one motor drives the "spread" action of both fingers synchronously and symmetrically about the palm.

The spread motion adds surprising dexterity. One design feature of the spread motion is that, unlike the curling motions of each finger, the spread is highly backdrivable, so that the spread compliance is controllable. By setting low spread compliance, the BarrettHand dynamically finds the lowest energy state as the fingers close, resulting in a firm and reliable grasp.

Q2: Can the two finger joint motions be controlled independently.?

A2: No, the two joints are controlled by one servo-motor. Although the mechanism behaves in an intelligent manner for grasping, we traded the second motor and motor electronics for the TorqueSwitch™ mechanism to save weight, bulk, heat, power, and cost.

Q3: How does the Torque Switch™ mechanism work and what is the clutch used for?

A3: See Section 7.3 for information on how the TorqueSwitch™ mechanism works.

Q4: What materials are the fingers made of, particularly the fingertips?

A4: Nylon is used for the fingertips and covers. The finger links are made of aluminum and the gearing is made of steel and bronze.

Q5: Is it possible to determine the instant when the TorqueSwitch™ is activated?

A5: It is possible to determine the approximate time when the TorqueSwitch™ is engaged by monitoring the velocity in RealTime mode. The velocity will approach zero and then will return to its original value. See Figure 32 for a graph of the velocity during TorqueSwitch™ activation.

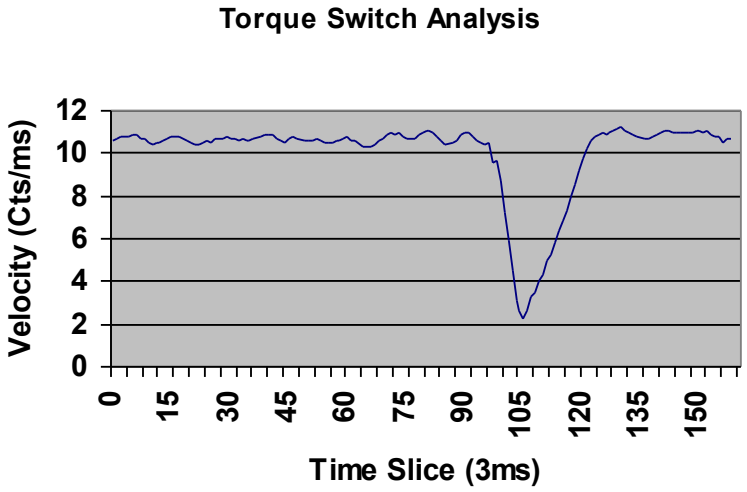


Figure 32 - TorqueSwitch Activation Graph

For more questions, please contact Barrett Technology Customer Service at (617) 252 - 9000.

GLOSSARY

API - An acronym for Application Program Interface, the set of commands that an application uses to request and carry out lower-level services performed by a computer's operating system

Backdrivability - Backdrivability is the measure of how accurately a force or motion that is applied at the output end of a mechanical transmission is reproduced at the input end. In a mechanical robot-like linkage, good backdrivablility means that a person can grab the enditp of the linkage and move it around effortlessly.

BarrettHand – The 1.1 kilogram dexterous robotic grasper as described in Section 1.1.2.

BarrettHand System - The entire system received from Barrett Technology, Inc. Includes all components as listed in Section 1.1, plus any additional options as described in Section 1.2.

Belleville Spring Washer - A conical washer that has geometry specifically formed to produce a desirable spring constant.

Cycle - (Finger) The equivalent to closing and opening the finger completely once, 35000 encoder counts.
(Spread) The equivalent to closing and opening the spread completely, 6200 encoder counts.

Firmware - Software that is embedded in a hardware device that allows reading and executing the software, but does not allow modification, e.g., writing or deleting data by an end user**.**

Grasp – (n.) The state in which an object has been firmly contained and secured by the BarrettHand.
(v1.) The method by which the BarrettHand closes its fingers around an object in order to secure it.
(v2.) The collective term for fingers one, two and three, as defined in the BarrettHand control software.

Graspcenter - The center of an object being grasped by the BarrettHand.

Hysteresis - The dependence of the state of a system on its previous history.

Idler Pulley - A fixed or adjustable disc support for a drive cable or belt. It is used in the BarrettHand for strain gage beam deflection.

Industrial Gripper - These grippers have only one degree of motion freedom, and can only execute an open/close motion. Because of the simple kinematics, the gripper fingers often must be specifically designed for the parts that have to be grasped. Product changes often require changes to the gripper assortment, increasing the product change-over time. Furthermore, an increase of the number of required grippers increases the number of required gripper changes during assembly.

Kinematics - The science of motion which treats motion without regard to the forces which cause it, specifically all the geometrical and time-based properties of position.

Lexan® - A water clear, high-impact resistant polycarbonate used to make the BarrettHand lab bench stand.

Pretension - The process of adding additional tension to a cable during the assembly process.

RealTime Mode - A control mode of the BarrettHand which allows you to control the motors in real-time. This mode allows you to monitor position, velocity, and strain gage values during motion and control the motors during motion.

RS-232 - RS-232 defines the specifications for encoding, transmitting, receiving, and decoding "characters". RS-232C is the most recent version of the EIA (Electronics Industry Association) standard for low-speed serial communication. It defines a number of parameters concerning voltage levels, loading characteristics and timing relationships.

Shoulder Screw - A fastener having a boss with a set diameter, usually for alignment purposes.

Spread - The patented motion of fingers F1 and F2 about the palm. This motion allows the fingers to be positioned around the palm for the best grasp.

Spur Gears - A gear having straight, parallel teeth that are perpendicular to the gear's face.

Supervisory Mode - A control mode of the BarrettHand which allows you to issue high-level commands to control motion and change parameters. The BarrettHand does not accept a new command until the previous command is finished.

Threaded Locking Ring - The removable circular ring at the base of the BarrettHand that is used to mount the hand, such as the Lexan® test stand or the arm adaptor.

TorqueSwitch™ - The patented coupling between the fingers two joints. This coupling allows the use of one motor to control two joints. When the inner link encounters an object with sufficient force, it will stop, while the outer link continues to close around an object. See Section 7.3.1for more information on the theory of operation.

Worm Gears - A long cylindrical gear with skewed teeth, making it capable of driving other gears.

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